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THIRD SERIES.

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THE

# AMERICAN JOURNAL OF SCIENCE.

[THIRD SERIES.]

ART. XXXVI.—*On the Relative Motion of the Earth and the Luminiferous Ether;* by ALBERT A. MICHELSON and EDWARD W. MORLEY.*

THE discovery of the aberration of light was soon followed by an explanation according to the emission theory. The effect was attributed to a simple composition of the velocity of light with the velocity of the earth in its orbit. The difficulties in this apparently sufficient explanation were overlooked until after an explanation on the undulatory theory of light was proposed. This new explanation was at first almost as simple as the former. But it failed to account for the fact proved by experiment that the aberration was unchanged when observations were made with a telescope filled with water. For if the tangent of the angle of aberration is the ratio of the velocity of the earth to the velocity of light, then, since the latter velocity in water is three-fourths its velocity in a vacuum, the aberration observed with a water telescope should be four-thirds of its true value.†

* This research was carried out with the aid of the Bache Fund.

† It may be noticed that most writers admit the sufficiency of the explanation according to the emission theory of light; while in fact the difficulty is even greater than according to the undulatory theory. For on the emission theory the velocity of light must be greater in the water telescope, and therefore the angle of aberration should be less; hence, in order to reduce it to its true value, we must make the absurd hypothesis that the motion of the water in the telescope carries the ray of light in the opposite direction!

On the undulatory theory, according to Fresnel, first, the ether is supposed to be at rest except in the interior of transparent media, in which secondly, it is supposed to move with a velociy less than the velocity of the medium in the ratio $\frac{n^2-1}{n^2}$, where $n$ is the index of refraction. These two hypotheses give a complete and satisfactory explanation of aberration. The second hypothesis, notwithstanding its seeming improbability, must be considered as fully proved, first, by the celebrated experiment of Fizeau,* and secondly, by the ample confirmation of our own work.† The experimental trial of the first hypothesis forms the subject of the present paper.

If the earth were a transparent body, it might perhaps be conceded, in view of the experiments just cited, that the intermolecular ether was at rest in space, notwithstanding the motion of the earth in its orbit; but we have no right to extend the conclusion from these experiments to opaque bodies. But there can hardly be question that the ether can and does pass through metals. Lorentz cites the illustration of a metallic barometer tube. When the tube is inclined the ether in the space above the mercury is certainly forced out, for it is incompressible.‡ But again we have no right to assume that it makes its escape with perfect freedom, and if there be any resistance, however slight, we certainly could not assume an opaque body such as the whole earth to offer free passage through its entire mass. But as Lorentz aptly remarks: "quoi qui'l en soit, on fera bien, à mon avis, de ne pas se laisser guider, dans une question aussi importante, par des considérations sur le degré de probabilité ou de simplicité de l'une ou de l'autre hypothèse, mais de s'addresser a l'expérience pour apprendre à connaitre l'état, de repos ou de mouvement, dans lequel se trouve l'éther à la surface terrestre."§

In April, 1881, a method was proposed and carried out for testing the question experimentally.‖

In deducing the formula for the quantity to be measured, the effect of the motion of the earth through the ether on the path of the ray at right angles to this motion was overlooked.¶

* Comptes Rendus, xxxiii, 349, 1851; Pogg. Ann. Ergänzungsband, iii, 457, 1853; Ann. Chim. Phys., III, lvii, 385, 1859.

† Influence of Motion of the Medium on the Velocity of Light. This Journal, III, xxxi, 377, 1886.

‡ It may be objected that it may escape by the space between the mercury and the walls; but this could be prevented by amalgamating the walls.

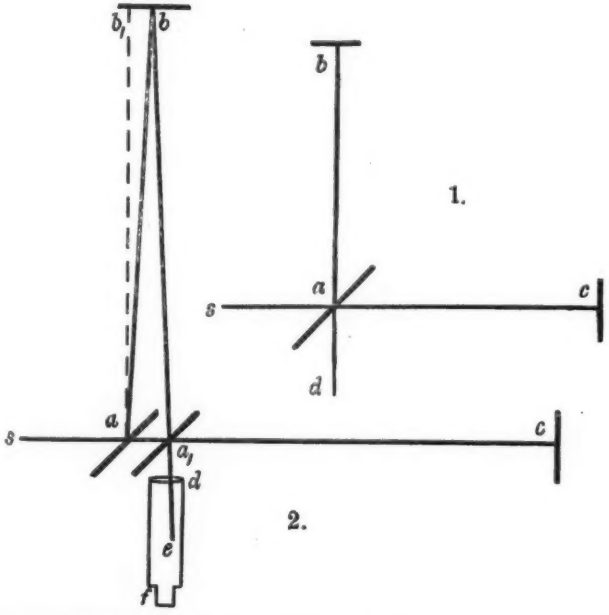
§ Archives Néerlandaises, xxi, 2me livr.

‖ The relative motion of the earth and the luminiferous ether, by Albert A. Michelson, this Jour., III, xxii, 120.

¶ It may be mentioned here that the error was pointed out to the author of the former paper by M. A. Potier, of Paris, in the winter of 1881.

The discusssion of this oversight and of the entire experiment forms the subject of a very searching analysis by H. A. Lorentz,* who finds that this effect can by no means be disregarded. In consequence, the quantity to be measured had in fact but one-half the value supposed, and as it was already barely beyond the limits of errors of experiment, the conclusion drawn from the result of the experiment might well be questioned; since, however, the main portion of the theory remains unquestioned, it was decided to repeat the experiment with such modifications as would insure a theoretical result much too large to be masked by experimental errors. The theory of the method may be briefly stated as follows:

Let *sa*, fig. 1, be a ray of light which is partly reflected in *ab*, and partly transmitted in *ac*, being returned by the mirrors *b* and *c*, along *ba* and *ca*. *ba* is partly transmitted along *ad*,




and *ca* is partly reflected along *ad*. If then the paths *ab* and *ac* are equal, the two rays interfere along *ad*. Suppose now, the ether being at rest, that the whole apparatus moves in the direction *sc*, with the velocity of the earth in its orbit, the direc-

* De l'Influence du Mouvement de la Terre sur les Phen. Lum. Archives Néerlandaises, xxi, 2me livr., 1886.

tions and distances traversed by the rays will be altered thus:—The ray $sa$ is reflected along $ab$, fig. 2; the angle $bab_{,}$ being equal to the aberration $=\alpha$, is returned along $ba_{,,}$ ($aba_{,}=2\alpha$), and goes to the focus of the telescope, whose direction is unaltered. The transmitted ray goes along $ac$, is returned along $ca_{,,}$ and is reflected at $a_{,,}$ making $ca_{,}e$ equal $90-\alpha$, and therefore still coinciding with the first ray. It may be remarked that the rays $ba_{,}$ and $ca_{,,}$ do not now meet exactly in the same point $a_{,,}$ though the difference is of the second order; this does not affect the validity of the reasoning. Let it now be required to find the difference in the two paths $aba_{,,}$ and $aca_{,}$.

Let $V$ = velocity of light.
$v$ = velocity of the earth in its orbit.
$D$ = distance $ab$ or $ac$, fig. 1.
$T$ = time light occupies to pass from $a$ to $c$.
$T_{,}$ = time light occupies to return from $c$ to $a_{,,}$ (fig. 2.)

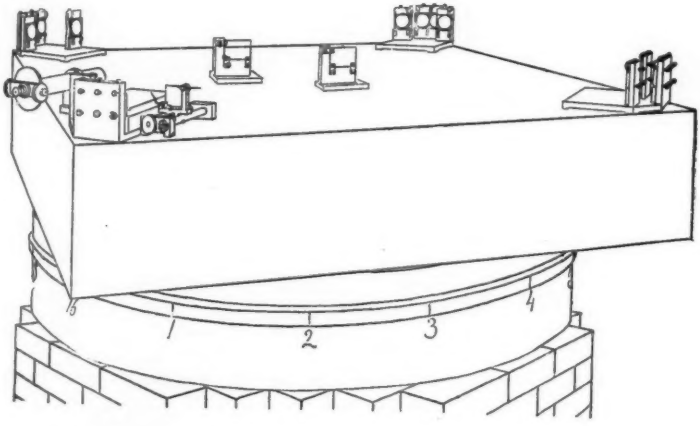
Then $T=\frac{D}{V-v}$, $T_{,}=\frac{D}{V+v}$. The whole time of going and coming is $T+T_{,}=2D\frac{V}{V^2-v^2}$, and the distance traveled in this time is $2D\frac{V^2}{V^2-v^2}=2D\left(1+\frac{v^2}{V^2}\right)$, neglecting terms of the fourth order. The length of the other path is evidently $2D\sqrt{1+\frac{v^2}{V^2}}$, or to the same degree of accuracy, $2D\left(1+\frac{v^2}{2V^2}\right)$. The difference is therefore $D\frac{v^2}{V^2}$. If now the whole apparatus be turned through 90°, the difference will be in the opposite direction, hence the displacement of the interference fringes should be $2D\frac{v^2}{V^2}$. Considering only the velocity of the earth in its orbit, this would be $2D\times10^{-8}$. If, as was the case in the first experiment, $D=2\times10^6$ waves of yellow light, the displacement to be expected would be 0·04 of the distance between the interference fringes.

In the first experiment one of the principal difficulties encountered was that of revolving the apparatus without producing distortion; and another was its extreme sensitiveness to vibration. This was so great that it was impossible to see the interference fringes except at brief intervals when working in the city, even at two o'clock in the morning. Finally, as before remarked, the quantity to be observed, namely, a displacement of something less than a twentieth of the distance between the interference fringes may have been too small to be detected when masked by experimental errors.

The first named difficulties were entirely overcome by mounting the apparatus on a massive stone floating on mercury; and the second by increasing, by repeated reflection, the path of the light to about ten times its former value.

The apparatus is represented in perspective in fig. 3, in plan in fig. 4, and in vertical section in fig. 5. The stone *a* (fig. 5)is about 1·5 meter square and 0·3 meter thick. It rests on an annular wooden float *bb*, 1·5 meter outside diameter, 0·7 meter inside diameter, and 0·25 meter thick. The float rests on mercury contained in the cast-iron trough *cc*, 1·5 centimeter thick, and of such dimensions as to leave a clearance of about one centimeter around the float. A pin *d*, guided by arms *gggg*, fits into a socket *e* attached to the float. The pin may be pushed into the socket or be withdrawn, by a lever pivoted at *f*. This pin keeps the float concentric with the trough, but does not bear any part of the weight of the stone. The annular iron trough rests on a bed of cement on a low brick pier built in the form of a hollow octagon.

3.

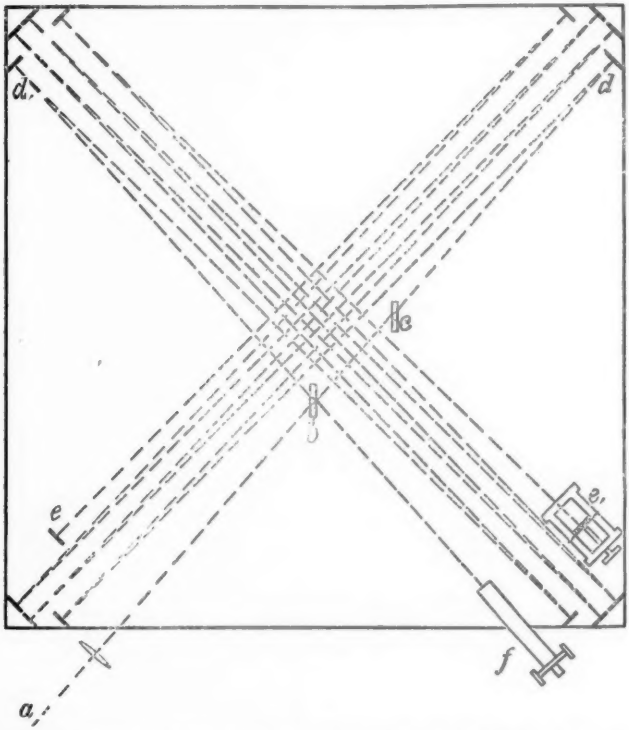



At each corner of the stone were placed four mirrors *d d e e* fig. 4. Near the center of the stone was a plane-parallel glass *b*. These were so disposed that light from an argand burner *a*, passing through a lens, fell on *b* so as to be in part reflected to $d_1$; the two pencils followed the paths indicated in the figure, *bdedbf* and $bd_1e_1d_1bf$ respectively, and were observed by the telescope *f*. Both *f* and *a* revolved with the stone. The mirrors were of speculum metal carefully worked to optically plane surfaces five centimeters in diameter, and the glasses *b* and *c* were plane-parallel and of the same thickness, 1·25 centimeter;

their surfaces measured 5·0 by 7·5 centimeters. The second of these was placed in the path of one of the pencils to compensate for the passage of the other through the same thickness of glass. The whole of the optical portion of the apparatus was kept covered with a wooden cover to prevent air currents and rapid changes of temperature.

The adjustment was effected as follows: The mirrors having been adjusted by screws in the castings which held the

4.

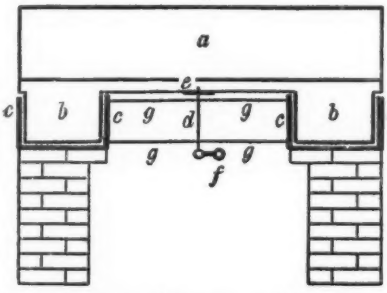



mirrors, against which they were pressed by springs, till light from both pencils could be seen in the telescope, the lengths of the two paths were measured by a light wooden rod reaching diagonally from mirror to mirror, the distance being read from a small steel scale to tenths of millimeters. The difference in the lengths of the two paths was then annulled by moving the mirror $e_1$. This mirror had three adjustments; it had an adjustment in altitude and one in azimuth, like all the other mirrors,

but finer; it also had an adjustment in the direction of the incident ray, sliding forward or backward, but keeping very accurately parallel to its former plane. The three adjustments of this mirror could be made with the wooden cover in position.

The paths being now approximately equal, the two images of the source of light or of some well-defined object placed in front of the condensing lens, were made to coincide, the telescope was now adjusted for distinct vision of the expected interference bands, and sodium light was substituted for white light, when the interference bands appeared. These were now made as clear as possible by adjusting the mirror $e$; then white light was restored, the screw altering the length of path was very slowly moved (one turn of a screw of one hundred threads to the inch altering the path nearly 1000 wave-lengths) till the colored interference fringes reappeared in white light. These were now given a convenient width and position, and the apparatus was ready for observation.

5.




The observations were conducted as follows: Around the cast-iron trough were sixteen equidistant marks. The apparatus was revolved very slowly (one turn in six minutes) and after a few minutes the cross wire of the micrometer was set on the clearest of the interference fringes at the instant of passing one of the marks. The motion was so slow that this could be done readily and accurately. The reading of the screw-head on the micrometer was noted, and a very slight and gradual impulse was given to keep up the motion of the stone; on passing the second mark, the same process was repeated, and this was continued till the apparatus had completed six revolutions. It was found that by keeping the apparatus in slow uniform motion, the results were much more uniform and consistent than when the stone was brought to rest for every observation; for the effects of strains could be noted for at least half a minute after the stone came to rest, and during this time effects of change of temperature came into action.

The following tables give the means of the six readings; the first, for observations made near noon, the second, those near six o'clock in the evening. The readings are divisions of the screw-heads. The width of the fringes varied from 40 to 60 divisions, the mean value being near 50, so that one division

means 0·02 wave-length. The rotation in the observations at noon was contrary to, and in the evening observations, with, that of the hands of a watch.

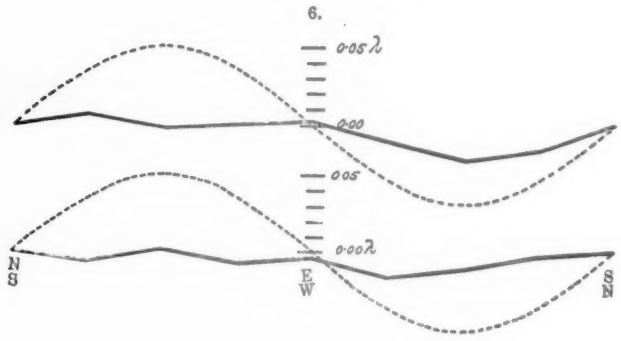
NOON OBSERVATIONS.

| | 16. | 1. | 2. | 3. | 4. | 5. | 6. | 7. | 8. | 9. | 10. | 11. | 12. | 13. | 14. | 15. | 16. |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| July 8..... | 44·7 | 44·0 | 43·5 | 39·7 | 35·2 | 34·7 | 34·3 | 32·5 | 28·2 | 26·2 | 23·8 | 23·2 | 20·3 | 18·7 | 17·5 | 16·8 | 13·7 |
| July 9..... | 57·4 | 57·3 | 58·2 | 59·2 | 58·7 | 60·2 | 60·8 | 62·0 | 61·5 | 63·3 | 65·8 | 67·3 | 69·7 | 70·7 | 73·0 | 70·2 | 72·2 |
| July 11.. ... | 27·3 | 23·5 | 22·0 | 19·3 | 19·2 | 19·3 | 18·7 | 18·8 | 16·2 | 14·3 | 13·3 | 12·8 | 13·3 | 12·3 | 10·2 | 7·3 | 6·5 |
| Mean..... | 43·1 | 41·6 | 41·2 | 39·4 | 37·7 | 38·1 | 37·9 | 37·8 | 35·3 | 34·6 | 34·3 | 34·4 | 34·4 | 33·9 | 33·6 | 31·4 | 30·8 |
| Mean in w. l. | ·862 | ·832 | ·824 | ·788 | ·754 | ·762 | ·758 | ·756 | ·706 | ·692 | ·686 | ·688 | ·688 | ·678 | ·672 | ·628 | ·616 |
| | ·706 | ·692 | ·686 | ·688 | ·688 | ·678 | ·672 | ·628 | ·616 | | | | | | | | |
| Final mean. | ·784 | ·762 | ·755 | ·738 | ·721 | ·720 | ·715 | ·692 | ·661 | | | | | | | | |

P. M. OBSERVATIONS.

| | | | | | | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| July 8..... | 61·2 | 63·3 | 63·3 | 68·2 | 67·7 | 69·3 | 70·3 | 69·8 | 69·0 | 71·3 | 71·3 | 70·5 | 71·2 | 71·2 | 70·5 | 72·5 | 75·7 |
| July 9..... | 26·0 | 26·0 | 28·2 | 29·2 | 31·5 | 32·0 | 31·3 | 31·7 | 33·0 | 35·8 | 36·5 | 37·3 | 38·8 | 41·0 | 42·7 | 43·7 | 44·0 |
| July 12..... | 66·8 | 66·5 | 66·0 | 64·3 | 62·2 | 61·0 | 61·3 | 59·7 | 58·2 | 55·7 | 53·7 | 54·7 | 55·0 | 58·2 | 58·5 | 57·0 | 56·0 |
| Mean ..... | 51·3 | 51·9 | 52·5 | 53·9 | 53·8 | 54·1 | 54·3 | 53·7 | 53·4 | 54·3 | 53·8 | 54·2 | 55·0 | 56·8 | 57·2 | 57·7 | 58·6 |
| Mean in w. l. | 1·026 | 1·038 | 1·050 | 1·078 | 1·076 | 1·082 | 1·086 | 1·074 | 1·068 | 1·086 | 1·076 | 1·084 | 1·100 | 1·136 | 1·144 | 1·154 | 1·172 |
| | 1·068 | 1·086 | 1·076 | 1·084 | 1·100 | 1·136 | 1·144 | 1·154 | 1·172 | | | | | | | | |
| Final mean. | 1·047 | 1·062 | 1·063 | 1·081 | 1·088 | 1·109 | 1·115 | 1·114 | 1·120 | | | | | | | | |

The results of the observations are expressed graphically in fig. 6. The upper is the curve for the observations at noon, and the lower that for the evening observations. The dotted curves represent *one-eighth* of the theoretical displacements. It seems fair to conclude from the figure that if there is any dis-




placement due to the relative motion of the earth and the luminiferous ether, this cannot be much greater than 0·01 of the distance between the fringes.

Considering the motion of the earth in its orbit only, this

displacement should be $2D\frac{v^2}{V^2}=2D\times10^{-8}$. The distance D was about eleven meters, or $2\times10^7$ wave-lengths of yellow light; hence the displacement to be expected was 0·4 fringe. The actual displacement was certainly less than the twentieth part of this, and probably less than the fortieth part. But since the displacement is proportional to the square of the velocity, the relative velocity of the earth and the ether is probably less than one sixth the earth's orbital velocity, and certainly less than one-fourth.

In what precedes, only the orbital motion of the earth is considered. If this is combined with the motion of the solar system, concerning which but little is known with certainty, the result would have to be modified; and it is just possible that the resultant velocity at the time of the observations was small though the chances are much against it. The experiment will therefore be repeated at intervals of three months, and thus all uncertainty will be avoided.

It appears, from all that precedes, reasonably certain that if there be any relative motion between the earth and the luminiferous ether, it must be small; quite small enough entirely to refute Fresnel's explanation of aberration. Stokes has given a theory of aberration which assumes the ether at the earth's surface to be at rest with regard to the latter, and only requires in addition that the relative velocity have a potential; but Lorentz shows that these conditions are incompatible. Lorentz then proposes a modification which combines some ideas of Stokes and Fresnel, and assumes the existence of a potential, together with Fresnel's coefficient. If now it were legitimate to conclude from the present work that the ether is at rest with regard to the earth's surface, according to Lorentz there could not be a velocity potential, and his own theory also fails.

### *Supplement.*

It is obvious from what has gone before that it would be hopeless to attempt to solve the question of the motion of the solar system by observations of optical phenomena *at the surface of the earth.* But it is not impossible that at even moderate distances above the level of the sea, at the top of an isolated mountain peak, for instance, the relative motion might be perceptible in an apparatus like that used in these experiments. Perhaps if the experiment should ever be tried in these circumstances, the cover should be of glass, or should be removed.

It may be worth while to notice another method for multiplying the square of the aberration sufficiently to bring it within the range of observation, which has presented itself during the

preparation of this paper. This is founded on the fact that reflection from surfaces in motion varies from the ordinary laws of reflection.

Let *ab* (fig. 1) be a plane wave falling on the mirror *mn* at an incidence of 45°. If the mirror is at rest, the wave front after reflection will be *ac*.

Now suppose the mirror to move in a direction which makes an angle $\alpha$ with its normal, with a velocity $\omega$. Let V be the velocity of light in the ether supposed stationary, and let *cd* be the increase in the distance the light has to travel to reach *d*. In this time the mirror will have moved a distance $\frac{cd}{\sqrt{2}\cos\alpha}$.

We have $\frac{cd}{ad} = \frac{\omega\sqrt{2}\cos\alpha}{V}$ which put $= r$, and $\frac{ac}{ad} = 1 - r$.

In order to find the new wave front, draw the arc *fg* with *b* as a center and *ad* as radius; the tangent to this arc from *d* will be the new wave front, and the normal to the tangent from *b* will be the new direction. This will differ from the direction *ba* by the angle $\theta$ which it is required to find. From the equality of the triangles *adb* and *edb* it follows that $\theta = 2\varphi$, $ab = ac$,

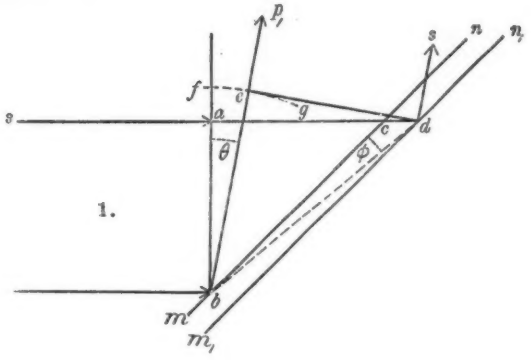
$$\tan adb = \tan\left(45° - \frac{\theta}{2}\right) = \frac{1 - \tan\frac{\theta}{2}}{1 + \tan\frac{\theta}{2}} = \frac{ac}{ad} = 1 - r,$$

or neglecting terms of the order $r^2$,

$$\theta = r + \frac{r^2}{2} = \frac{\sqrt{2}\omega\cos\alpha}{V} + \frac{\omega^2}{V^2}\cos^2\alpha.$$

Now let the light fall on a parallel mirror facing the first, we should then have $\theta' = \frac{-\sqrt{2}\omega\cos\alpha}{V} + \frac{\omega^2}{V^2}\cos^2\alpha$, and the total deviation would be $\theta + \theta' = 2\rho^2\cos^2\alpha$ where $\rho$ is the angle of aberration, if only the orbital motion of the earth is considered. The maximum displacement obtained by revolving the whole apparatus through 90° would be $\Delta = 2\rho^2 = 0{\cdot}004''$. With fifty such couples the displacement would be $0{\cdot}2''$. But astronomical observations in circumstances far less favorable than those in which these may be taken have been made to hundredths of a second; so that this new method bids fair to be at least as sensitive as the former.

The arrangement of apparatus might be as in fig. 2; *s* in the focus of the lens *a*, is a slit; *bb cc* are two glass mirrors optically plane and so silvered as to allow say one-twentieth of the light to pass through, and reflecting say ninety per cent. The intensity of the light falling on the observing telescope *df*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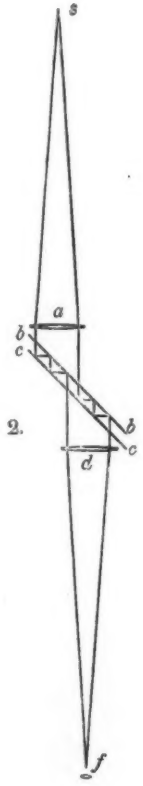
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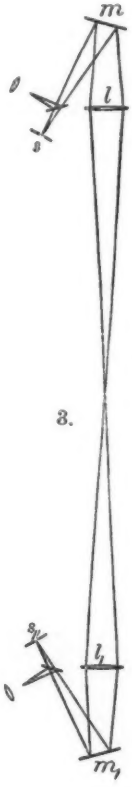
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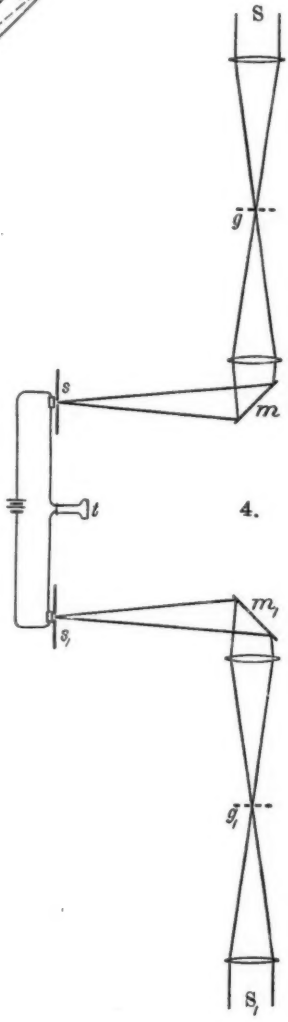
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would be about one-millionth of the original intensity, so that if sunlight or the electric arc were used it could still be readily seen. The mirrors $bb_,$ and $cc_,$ would differ from parallelism sufficiently to separate the successive images. Finally, the apparatus need not be mounted so as to revolve, as the earth's rotation would be sufficient.

If it were possible to measure with sufficient accuracy the velocity of light without returning the ray to its starting point, the problem of measuring the first power of the relative velocity of the earth with respect to the ether would be solved. This may not be as hopeless as might appear at first sight, since the difficulties are entirely mechanical and may possibly be surmounted in the course of time.

For example, suppose (fig. 3) $m$ and $m_,$ two mirrors revolving with equal velocity in opposite directions. It is evident that light from $s$ will form a stationary image at $s_,$ and similarly light from $s_,$ will form a stationary image at $s$. If now the velocity of the mirrors be increased sufficiently, their phases still being exactly the same, both images will be deflected from $s$ and $s_,$ in inverse proportion to the velocities of light in the two directions; or, if the two deflections are made equal, and the difference of phase of the mirrors be simultaneously measured, this will evidently be proportional to the difference of velocity in the two directions. The only real difficulty lies in this measurement. The following is perhaps a possible solution: $gg_,$ (fig. 4) are two gratings on which sunlight is concentrated. These are placed so that after falling on the revolving mirrors $m$ and $m_,$ the light forms images of the gratings at $s$ and $s_,$ two very sensitive selenium cells in circuit with a battery and a telephone. If everything be symmetrical, the sound in the telephone will be a maximum. If now one of the slits $s$ be displaced through half the distance between the image of the grating bars, there will be silence. Suppose now that the two deflections having been made exactly equal, the slit is adjusted for silence. Then if the experiment be repeated when the earth's rotation has turned the whole apparatus through 180°, and the deflections are again made equal, there will no longer be silence, and the angular distance through which $s$ must be moved to restore silence will measure the required difference in phase.

There remain three other methods, all astronomical, for attacking the problem of the motion of the solar system through space.

1. The telescopic observation of the proper motions of the stars. This has given us a highly probably determination of the direction of this motion, but only a guess as to its amount.

2. The spectroscopic observation of the motion of stars in the line of sight. This could furnish data for the relative

motions only, though it seems likely that by the immense improvements in the photography of stellar spectra, the information thus obtained will be far more accurate than any other.

3. Finally there remains the determination of the velocity of light by observations of the eclipses of Jupiter's satellites. If the improved photometric methods practiced at the Harvard observatory make it possible to observe these with sufficient accuracy, the difference in the results found for the velocity of light when Jupiter is nearest to and farthest from the line of motion will give, not merely the motion of the solar system with reference to the stars, but with reference to the luminiferous ether itself.

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ART. XXXVII.—*On the Existence of Carbon in the Sun. Contributions from the Physical Laboratory of Harvard University;* by JOHN TROWBRIDGE and C. C. HUTCHINS.

[From the Proceedings of the American Academy of Arts and Sciences, vol. xxxiii.]

FROM the presence of absorption bands in the solar spectrum at high altitudes, Captain Abney has been led to believe in the existence of certain hydrocarbons between the earth and the sun; and Siemens's theory of the conservation of solar energy depends upon the supposed existence of carbon vapor in interplanetary space. It is not our purpose to discuss Abney's observations, or the truth of Siemens's hypothesis. We wish to call attention to the remarkable character of the carbon spectrum, formed by the voltaic arc in air between carbon terminals; and to draw attention to the evidence presented by the juxtaposed solar spectrum of the existence of carbon in the sun.

In our early experiments the carbon terminals between which the voltaic arc was formed were heated several hours, while a stream of chlorine gas was passed over them. This operation was not entirely successful in removing metallic impurities. Subsequently we discovered that the spectra of these impurities could be readily distinguished from the marked fluted carbon spectrum, and we therefore employed the ordinary compressed carbon sticks employed in electric lighting.

For our work the nicest adjustment of slit was necessary, in order that no displacement of spectrum lines could possibly occur when the carbon spectrum was photographed in juxtaposition with the solar spectrum. This was accomplished by the use of a slit, the jaws of which opened equally.

One of Rowland's concave gratings, of 21 feet 6 inches in curvature and 14,000 lines to the inch, was employed. In order to avoid any possible displacement of the photographic camera during the operation of photographing the carbon spectrum immediately below the solar spectrum, a drop shutter was arranged directly in front of the sensitive plate, the movement of which was independent of any movement of the camera. Preliminary experiments showed us the importance in this work of employing a spectroscope of great dispersion and of fine definition, giving also a normal spectrum. The use of a prism spectroscope would undoubtedly have masked the phenomena we have observed. For our purpose, therefore, Rowland's apparatus was peculiarly advantageous.

Our experiments lead us to conclude that there is positive evidence in the solar spectrum of the existence of carbon in the sun. Before giving an account of our experiments in detail, a few observations may not be considered out of place.

One who studies the solar spectrum by itself, and who has had no experience in the formation and observation of metallic spectra, is apt to regard the dark lines in the solar spectrum as fixed in character and condition. A line which is seen by one observer, and not by another, is generally regarded as a terrestrial line formed by absorption in the earth's atmosphere. Certain lines are well known to be due to the terrestrial absorption, as can be easily proved by their appearance when the sun is observed at sunset, when the rays of light have to penetrate a greater thickness of the earth's atmosphere than at midday. The shifting layers of vapor in the sun's atmosphere also may, in certain cases, obliterate or strengthen certain lines of metal. To understand this it is only necessary to extend the reasoning of the conservation of energy to the subject. It is a common lecture experiment to reverse the metallic lines by passing the rays of light produced by the vapor of the element through a layer of vapor colder than that of the source of the rays. The energy of the rays is thus absorbed in heating the colder layer. When the temperature of the vapor is increased, and becomes equal to that of the source, no reversal takes place. Thus, on the sun's surface the conditions for a reversal may be wanting at certain times, and faint lines may become bright. Their brightness may not be sufficient to affect the general illumination of the solar spectrum of which they form a part. Conditions may arise, moreover, in which the temperature of the reversing vapor may be called critical,—at such a temperature that the faint reversal is sufficient to extinguish the bright line of a metal without producing a well-defined dark line. At certain epochs, also, the temperature of the vapor of any element in the sun may be higher than at any other time; and certain

lines may thus appear which are wanting when the temperature falls. One is forced to these conclusions in observing the conditions under which the varying character of metallic spectra are produced. For instance, we have caused the rays from iron vapor to traverse a long and dense layer of iron vapor, and have observed that the strength of the lines and the number of reversals have been largely increased. In another experiment, the lower carbon of the electric lamp we employed occupied the center of an electro-magnet. This was accomplished by passing the carbon through a hollow iron cone, and surrounding the latter by layers of wire, through which the electrical current employed in generating the light passed. In this case the electric arc was spread out at right angles to the pole of the magnet, into a fan-like, intensely hot flame which roared loudly, and which rarefied, so to speak, the iron vapor between the carbon terminals. The strength of the lines and the number of reversals were diminished under this new condition.

Another phenomenon may happen. When an excess of the vapor of one metal floats over or is mixed with that of another, the lines of one metal are superimposed upon those of another in the solar spectrum, and the stronger spectrum of one element may easily obliterate the weaker spectrum of another. Thus we have succeeded in completely obliterating the fluted spectrum of carbon in the green and blue, by photographing upon it the spectrum of iron, of nickel, and cerium. A species of composite photograph was thus obtained. It is possible that in the future Galton's ingenious method of composite photography may be applied to the solar spectrum; and by a judicious selection of photographs of the elements, a composite photograph may be obtained which closely resemble portions of the solar spectrum, and will enable us to judge of the composition of the reversing layers of the sun.

To the varying conditions which we have thus outlined are due, we believe, the disappearance in the sun's spectrum of the marked fluted spectrum of carbon in the green and blue portions.

A careful examination of the fluted spectrum of carbon, however, with the juxtaposed solar spectrum, discloses a remarkable fact: while traces of obliteration of the evidence of carbon vapor are seen, yet the general character of the lines in the solar spectrum immediately juxtaposed with the fluted spectrum of carbon near H lead us to believe that there is unmistakable evidence of the existence of carbon vapor in the sun. When the arrangement of the fine lines of the spectrum of carbon is plotted as a curve, and that of the dark lines in the solar spectrum immediately above the carbon spectrum is

also plotted, the two curves have a remarkable similarity in character, running with a slight convexity toward one axis.

In the first fluting at wave-length 3883·7 within the limit of ten wave-lengths, over 28 of the spaces between the fine bright lines of the flutings coincide with dark lines immediately in juxtaposition in the solar spectrum. When we consider that the progressive arrangement of these lines is exactly the same both in the spectrum of carbon and that of the sun, we cannot consider that this coincidence is the result of chance. On examining the spectrum of carbon in the region near H still further, a remarkable number of coincidences of the spaces between the bright lines of the carbon spectrum with dark lines in the solar spectrum will be observed. We are led, therefore, to conclude that the fluted spectrum of carbon is an example of the reversal of the lines of a vapor in its own vapor. Fluted spectra occur at comparatively low temperatures. When carbon is ignited, we have at first a continuous spectrum. When the temperature increases and the carbon is volatilized, fluted spectra occur, which consist of interruptions of the continuous spectrum by fine line reversals occurring in harmonic order. The same phenomenon can be observed in the spectrum of iron lines: through the center of an iron line, when a sufficient amount of iron vapor surrounds the voltaic arc in which iron is volatilized, reversal lines are always seen. Now if the iron lines were arranged in regular order, the reversals would also be in like regular order, and would coincide with similar reversals in the solar spectrum. Assuming the conditions at the sun's surface to be the same as those we have in the voltaic arc, when carbon is volatilized, the character of the carbon spectrum should exactly agree with the character of the solar spectrum juxtaposed. This is found to be true to a remarkable degree in comparing portions of the solar spectrum with portions of the fluted spectrum of carbon beginning at wave-length 3883·7.

Our hypothesis leads us to conclude, that, at the point of the sun's atmosphere where the carbon is volatilized, so as to produce the peculiar arrangement of reversals observed, the temperature of the sun approximates to that of the voltaic arc.

ART. XXXVIII.—*History of the Changes in the Mt. Loa Craters;* by JAMES D. DANA. (With Plates II, III, IV.) Part I, KILAUEA.

[Continued from page 97, vol. xxxiv.]

SUPPLEMENT.

A JOURNEY of ten weeks (involving over ten thousand miles of travel) has enabled me to carry out the purpose expressed in my communication of August last. I have thus succeeded in supplementing the work of that one day at Kilauea out of five on Hawaii to which I was restricted in 1840, by one week at Kilauea out of two on Hawaii, besides having one week for the extinct crater of Haleakala and other parts of Maui, an island not before visited, and two for the island of Oahu.

The original objects of the trip were: (1), to examine the great lava-lake of Kilauea, Halema'uma'u, in its existing state of moderate activity; (2), to re-examine the rocks and walls of the crater; and (3), to compare the lines in the Wilkes map with the present outline of the crater, in order especially to remove doubts about the map before using it as a basis for historical conclusions.*

In this supplement I present such of the facts from my observations on the islands as belong to the *history* of Kilauea, reserving the rest about the crater for the "Summary and Conclusions" which will follow in another number, and the observations elsewhere for a later number. I introduce also a few facts from other sources. For the convenience of reference the map of the Government Survey is here reproduced (Plate II).

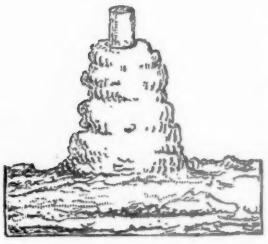
1. *Fissure ejections of* 1832 *and* 1868.—It is stated in early parts of this paper† that in 1832, and again in 1868, lavas were ejected through the depressed summit plain between Kilauea and Kilauea-iki. My observations enable me to state that Mr. Brigham's map, on page 89 of this volume, gives the position of the outflow of 1832, and the map of the Government Survey, Plate II, shows that of 1868. The lava of the latter stream has still a lustrous surface and little vegetation upon it, while the earlier has become weathered, and is much under shrubbery.

* I owe much of my success in the carrying out of my plans at the islands to Professor W. D. Alexander, Surveyor General of the Islands, Rev. Wm. C. Merritt, President of Oahu College, and Mr. J. S. Emerson, one of the assistants of the Government Survey, and am greatly indebted also to many others for kindnesses in various ways.

† Vol. xxxiii, p. 445 and this vol. p. 92.

The lavas of 1868 were ejected from a fissure nearly a hundred yards long, and flowed over the plain without descending into Kilauea, a portion of it covering part of the stream of 1832, as already stated. Many small trees standing in its course have now a rough cylindrical encasement of lava about their charred bases, which reaches to a height of from two to two and a half feet or more above the level of the flow, thus showing that the viscid stream, when reaching the trees on its way down the slope, had greater height of surface than afterward when the flow had passed by and its final level was attained.

1.



2. *Lower pit in* 1837.—The lower pit of 1832 had become very nearly obliterated, according to Mr. S N. Castle, of Honolulu, by the latter part of August, 1837, as he informed me in August last. He found cones active in all parts of the crater.

3. *The "lower pit" of* 1868.—Mr. Nordhoff, in his "Northern California, Oregon and the Sandwich Islands,"* p. 45, says, speaking of the outbreak of Kilauea in 1868, "suddenly, one day, the greater part of the lava floor sank down or fell down a depth of about five hundred feet, to the level where we now walked. The wonderful tale was plain to us [March 3, 1873] as we examined the details on the spot. It was as though a top-heavy and dried-out pie-crust had fallen in at the middle, leaving a part of the circumference bent down but clinging at the outside of the dish." Mr. Nordhoff's statement as to the depth of the lower pit was evidently quoted, and is not independent testimony, but his comparison suggested by the sight of the place, sufficiently intelligible to an American, attests to the reality of the subsidence.

A letter from Mr. J. M. Lydgate, dated Laupahoehoe, Hawaii, August 10, 1887, contains the information that his map, reproduced on page 94 of this volume, was made after a survey in June of 1874. He also stated that the depth of the lower pit of 1868, was at that time, as nearly as he could now remember, "about thirty or forty feet where the trail crossed it."

4. *Level of the Great South Lake in January*, 1878.—Mr. C. J. Lyons, of the Government Survey Office, told me that on January 1, of 1878, he obtained, by means of a theodolite, 325 feet as the level of the lavas of Halema'uma'u below the datum mark at the Volcano House.

* 1874. New York and also London.

5. *Further testimony as to the eruption of* 1879.—The following testimony confirms the brief statement, on page 94, with regard to the fact of this eruption. It is from the hotel book of the Volcano House.

1878. July 20. "Halema'uma'u in a most active state." M. P. Robinson.—Sept. 20. "Very active." J. Mott Smith.—Nov. 24. "Very active; lava within a foot of top of bank."

1879. Jan. 8. "South Lake with lava 50 feet below the rim and boiling like water." Wm. Gardner.—March 19. "Large and bright lake."—April 15. "Light wonderful."

1879. April 21. "Bottom dropped out of crater." Wm. H. Lentz, of Honolulu.—Ap. 23. "Found the ——— thing extinct." G. Grœper.—Ap. 28. "Almost extinct; some vapors." Rev. A. O. Forbes, of Honolulu.—Ap. 29. "No fire at all." "Lake quite empty." J. Day.

1879. June 24. "Throwing up jets of lava; both lakes active; looks like a fountain of fire from the verandah of the Volcano House." Wm. H. Lentz.—July 2. "All traces of two lakes of July, 1878, obliterated, and instead an enormous single lake, which was quite active;" "lava thrown up 50 feet." Wm. Tregloan, of Honolulu.

The eruption was a discharge of the lavas of the Great Lake, as in that of March, 1886; and the lavas began to return in two months or sooner. Miss C. F. Gordon Cummings,* who was at the crater in the autumn of 1879, learned from others that the discharge took place on April 21st.

6. *Premonitions and effects of the eruption of March*, 1886, *in the vicinity of the Volcano House.*—The situation of the Volcano House is shown on plate II. It is within the great area of subsidence, northeast of Kilauea, where are many fault-plane precipices and numerous open fissures, many of the latter discharging freely hot air and steam, fumarole-like, and some of the deeper sending up also sulphurous acid gas. The large depressed area adjoining the house on the west is a true Solfatara, and the well-known extensive sulphur bank within it,—the only real sulphur bank about Kilauea at the present time—is hardly four hundred yards distant. A bathing house for vapor baths is near by, which is supplied with hot vapors from one of the fissures. The proprietor of the house, Mr. J. H. Maby, informed me that on the afternoon of the 6th of March, (Saturday) wishing to take a bath, he found at repeated visits the vapors at the bath-house too hot for it, and finally gave it up. At $9^h$ 30′ of that evening a slight earthquake was felt, and at $9^h$ 45′, three others, which made "thud-like sounds," or

* Fire Fountains of the Kingdom of Hawaii, 2 vols., 8vo, London, 1883.

"like the fall of a meal-bag on the floor." At 10$^h$ the light over Halema'uma'u, before very brilliant, suddenly disappeared; the discharge had taken place. Through Sunday morning the escape of vapors from the fissures of the Solfatara region near the Volcano House went on, but it ceased entirely on Tuesday, and the stoppage continued through Wednesday and Thursday. Afterwards the discharge was gradually resumed.

The forty-one earthquakes which are reported as having occurred during the night, though not strong enough to shake down furniture in the house or crockery from shelves, felt to Mr. Maby as if the foundations of the house were giving way. The shocks have been attributed to the down-plungings of the walls of Halema'uma'u; but the intervening distance, 12,000 feet, is too great for such an effect; moreover, deep fissures were opened near by, along the road just east of the Volcano House, which are still steaming, and these suggest a sufficient cause.

The following facts are from the author's recent observations.

7. *Contrast in activity between the second week in November, 1840, and August 11 to 18, 1887.*—In November, 1840, the crater, over a very large interior region, including that of Halema'uma'u, was nearly a thousand feet in depth, and to the black ledge, or terrace, 650 feet. *Now*, as Messrs. Emerson and Dodge have reported,* the floor is everywhere less than 500 feet below the level of the Volcano House; the central part is but 400 to 360 feet; the Halema'uma'u border mostly under 340 feet; and, further, the floor slopes in all directions from Halema'uma'u to the base of the cliffs. The lava streams cover up all debris at the base. A few stones were observed imbedded in the lava that must have fallen during the flow before the lava had cooled.

In 1840, the Great South Lake—situated at the bottom of a southern prolongation of the lower pit nearly half a mile wide—was in fiery ebullition throughout, throwing up vertical lava-jets to a height of thirty feet or so over a surface of 1000 by 1500 feet; and it was so brilliant that at night the projecting angles and jetting points of the lofty black walls of Kilauea were lighted up throughout the whole circuit of the pit, and so hot as to forbid approach within 250 yards. *Now*, the Halema'uma'u basin, while a little over half a mile in mean diameter,* has at center a black and gray cone made of lava blocks and earth (as described by Mr. Dodge), sending forth vapors freely from apertures about it, but affording no signs of liquid lavas within; for even in a night view the clouds of vapors were

* This Journal, last volume, (pages 87, 98).

lighted up not over the cone, but east and west of it. Figure 2 is a view of the cone without its vapors, taken from the Vol-

2.

Cone in Halema'uma'u.

cano House; it is seen to rise out of an abrupt depression, which is that of Halema'uma'u. The narrow part of the depression to the left is the basin of the adjoining "New Lake." Plate III, representing the north end of the cone, with the bottom of the Halema'uma'u basin outside of it, illustrates its agglomerate nature. It is literally debris-made, and the debris is chiefly that from fallen walls, not the cinders or loose scoria derived from the ejections of a central vent. The plate shows also the character of the wall of Halema'uma'u, the stratification in the wall of Kilauea, and, above the latter, snow-capped Mt. Loa. The photograph from which the plate was engraved was taken in January last.

The only lake with active fires that was open to view in August last, was that on the west side of the cone; the more southern and the southeastern borders were swept by the wind-drifted vapors. The lake was but 150 by 175 feet in its diameters. It was mostly crusted over, but showed the red fires in a few long crossing lines (fissures), and in three to five open places, half way under the overhanging rock of the margin where the lavas were dashing up in spray and splashing noisily, with seemingly the liquidity of water. Now and then the fire places widened out toward the interior of the lake, breaking up the crust and consuming it by fusion; yet at no time was there a projection of the lavas in vertical jets in a free-boiling way; nor was it too hot to stand on the border of the lake if only the face were protected. Although relatively so quiet, the mobility of the brilliant splashing lavas made it an intensely interesting sight. Occasionally the red fissures widened by a fusing of the sides as the crust near by heaved, and the lavas flowed over the surface. It was evident from the cooled streams outside, that now and then more forcible movements take place, followed by outflows over the margin.

8. *The ordinary lava-stream, Pahoehoe of the Islanders.*—The ordinary Kilauea lava-stream made by overflowing or outflowing of the thoroughly fused lavas is remarkably smooth in surface. This is well seen in the small overflowings from the lava-lake, the lavas being so liquid that it may be dipped up

with a ladle or even a spoon.* But through one way and another it usually becomes uneven in general surface, wrinkled, billowy, hummocky, knobbed, fractured, and sometimes caved in or shoved out of place when fractured; and other rough features come from the adding of stream to stream. Plate IV shows something of the uneven character, but not the larger irregularities. Part of these rough features are owing directly or indirectly to crusting by surface-cooling, thinly or deeply, during the flow. Wrinkles, "billows" or domes, knobby and ridgy surfaces are depended on this condition, as well as the tunnel-like chambers and many of the shallower fractures. The fractures often lead to displacements of masses, and also to outflows of lava. In these outflows, the still liquid lava beneath the crust oozes out and fills the crack and so makes a seam, the immediate cooling at surface preventing a further flow; or the lavas pour out in larger volume and spread away in streamlets. Or the crust yields at a thin spot and the liquid stuff pushes out, but becomes at once stiffened and stopped by cooling and so makes projecting knobs of various sizes, shapes and lengths. Another source of uneven surface and cracks is the moisture beneath the flowing lavas of the crater, which is always present at greater or less depths since rain falls every other day or oftener.

The wrinkles and dome-shaped elevations or "billows" are remarked upon beyond.

The "pahoehoe" of Kilauea is of two kinds: (1) the ordinary lava of the mountain-side; and (2) that of the crater, distinguished by its separable scoriaceous glassy crust. The crust is a *crater*-feature, for I have not seen it on the lavas of the mountain outside. The crust, at the present time, is half an inch to two inches thick, and thickest in the vicinity of Halema'uma'u. As before described, it separates easily from the stony lava underneath; and this is so because the vesicles along the plane of junction are much larger than elsewhere.

The stony lava beneath the glassy crust, making the body of the Kilauea streams, and many feet or yards thick is remarkably solid, having relatively few vesicles. Moreover, this light gray to black basalt contains commonly very little chrysolite (olivine). The most chrysolitic which I observed in Kilauea rocks was from one of the layers near the bottom of the precipice in Waldron's ledge, 100 feet or so above the level of the Kilauea floor. The stratified lavas of the *walls* of Kilauea, so far as examined, have the same compact stony character as those of the bottom, the same sparing distribution of air-vesicles. Some of the kinds, of light gray color, are almost wholly free from vesicles. But while the upper part of a layer in the walls is sometimes scoriaceous, it is never covered with a glassy crust.

* I have a spoon filled with lava that was dipped up by Mr. Coan.

The lavas exuded through the crust from the liquid mass below, above alluded to as making seams, streamlets and knobby surfaces, are covered sometimes with separable scoriaceous glassy crust, though commonly having a solid glassy exterior half an inch or so thick.

9. *The wrinkled surfaces or tapestry-like folds of the flowing lavas.*—While looking at the small lava lake, the making of the tapestry-like folds, so common a fluidal feature of the lava-streams of Hawaii, was well exemplified. A stream of lava came out from beneath the cone and flowed obliquely across the lake, making the folds or wrinkles by its onward movement in the thin crust which surface cooling had produced; and the wrinkles were convex down-stream because of the greater velocity at centre. The accompanying figure repre-

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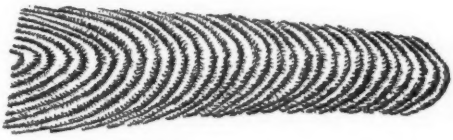


sents, reduced, a small portion of the stream. At one time a lateral shove took place along one of the fissures in the crust of the lake, and the next moment the margin was rolled over into a long fold or wrinkle, and then by the more rapid movement of the middle portion, a large part of the fold became twisted into a rope. Thus fold may follow fold, and make a group or series of rope-like folds; and tapestry wrinkles become rope-like by a similar method.

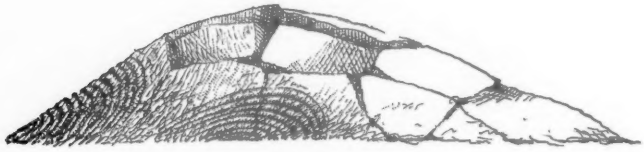
The tapestry-like folds of the surface of streams are sometimes folds simply in the scoria-crust; but they commonly consist of the more solid lava also, or of that alone where the scoria-crust is absent. This rope-making goes on over parts of outflowing lava streams. Sometimes, in connection with the making of the long ropes, the crust, where thin, becomes bent upward so as to have a long empty space a foot or two deep beneath the brittle cover. It is a trap for the incautious traveler, but it usually startles without injuring, yet serves to point a paragraph about the dangers of the crater.

On Plate IV, which represents the general aspect of the floor of Kilauea (and of many lava flows elsewhere) there are examples of the tapestry-like folds, and some of the small folds are twisted rope-like.

10. *Dome-shaped bulgings of lava-streams made sometimes, if not generally, after the stream has flowed on.*—Such bulgings, the

"billows" or "hummocks," in part, of some describers, are common here and there over a stream and often have a height of fifteen to twenty feet. I have attributed them, in my Exploring Expedition Report, to steam made from moisture underneath. This view is sustained by the actual arching of the stratum, often seen in a cross-section, and also by the cavity or cavities within and the broken or fallen-in top. Some seem to have been further crushed by the push of a subsequent lava flow.

4.



The sulphur vapors may also aid in making these dome-shaped elevations. And when so, the space below may have, as the facts show, the roof covered with a crust and stalactites of glauber salts, or with a thin crust of gypsum; the vapors having contributed material for the sulphuric acid, and the labradorite of the lavas, the soda or lime.

In many places evidence was plain that bulging had taken place after the flow of the lava-stream though before complete consolidation. This evidence was afforded by the tapestry folds on the bulged surface, they being upside down; that is, the folds were often convex upward instead of downward, as in the figure. The tapestry folds indicate the direction of movement; and, when thus upside down, they prove that they had been turned out of their original position.

11. *Flames from the lava-lake.*—The party which made a night visit to the small lava-lake in Halema'uma'u, the evening before we left the place, saw flames, similar in all respects to those reported by Mr. Brigham.* They were seen to rise where heavings and breakings of the lava-crust took place, and not where the fires were most active. The flames were one to three feet in height. They were very pale in color and slightly greenish rather than bluish. I cannot claim myself to have seen the flames—the rains of the evening, and a cold from a thorough wetting the day before, having prevented my joining the party. But critical observers were of the number—as Mr. Emerson of the Government Survey, President Merritt of Oahu College, Rev. S. E. Bishop and others, and the testimony was unanimous.

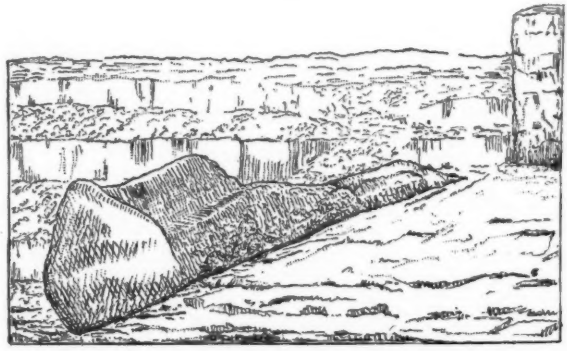
* This volume, pages 91, 95.

12. *Floating Island of* 1882 *to* 1886, *now stranded.*—Mr. Emerson speaks of the stranded floating island of New Lake as over sixty feet high, and describes well its surroundings.* I found, from an early photograph, that not long after it began its floating career it had the form shown in the following figure, as if it were a portion of a solidified lava-stream, either taken

5.

from the sides of the lake, where undermining by the dashing and fusing lavas might have separated it, or more probably derived from depths below and floated upward by the rising lavas. An examination of the stranded island showed that it consisted of the ordinary Kilauea lava, not much vesiculated, but enough to enable it easily to float. Further, it indicated great change in form since its first appearance. It lies on the bottom of the emptied lake-basin, as seen in the following figure (taken from a photograph). Two other photographs

6.



which I obtained at Honolulu, show intermediate forms, but they do not differ greatly from figure 5 above. The change in form might have come both from the projection over it of liquid lavas, and from erosion of its sides by the fusing heat. It is not known how much of it was beneath the surface of the lava; but the reader may perhaps satisfy himself on this point.

13. *The fissured borders of Kilauea.*—Besides the great fissures of the northern border of the crater, near the path of

* This Journal, xxxiii, 91, 1886.

descent with the subsided belts between, and the many fissures of the Solfatara depression just back, others occur farther north and east, to a wall, about forty feet high, which is evidently a fault wall. This wall is about 2000 feet from Kilauea at the northwest corner, and diverges eastward to about 5000 feet, and then bends around southward so as to embrace Kilauea-iki within the large northern border region of fissures and subsidence.

Deep and wide rents extend also along the whole western border of Kilauea, generally two or more together; and near the highest station, Uwekahuna, there are six of them parallel to one another. South of this station, between it and the southwest angle of the crater, the fissures are continued over a large depressed border 500 to 1,500 feet wide, lying between a precipitous ridge—fault-plane—on the west and the crater. North of Uwekahuna the evidences of subsidence now visible are small; but south of it the surface has different terrace levels, showing great and various sinkings of the surface. Almost in front of Uwekahuna, bordering the Kilauea wall, there is a surface, 200 to 298 feet below the level of this station, according to the Government maps, which is plainly, as seen from below, a result of subsidence; and various other terrrace-levels exist farther south. On the east side of Kilauea, also, there are fissures parallel to the walls; and large depressed areas exist between Kilauea and the two adjoining craters. Fissures extend northward to the east of Kilauea-iki, as noticed by the Wilkes expedition in 1840, and new openings there, near the Keauhou road, were reported as opened in March, 1886, at the time of the eruption.

The wall on the northeast side of Kilauea, near the path of descent, called Waldron's ledge (after a purser in the Wilkes expedition) is one of the highest and most stable parts of the walls, being but eleven and a half feet below the level of the Volcano House datum. It is a bare-faced, vertical precipice, showing stratified lavas to the top. Like Uwekahuna, it seems to be an exception to border instability. But it stands on the brink of the most unstable region—that of the north side. In a walk along the base of the precipice I found a fresh uncovering of the rock at bottom for a height of two to three inches, showing that a recent sinking adjoining it had taken place, or that one was then in progress.

This border belt of fissures and subsidences, if reckoned as part of the Kilauea fire-region, or region of disturbance, adds 5000 feet to the length of the region, and nearly doubles the width across the northern half.

There are long fissures also, over the region southwest of the crater, some of which were reported by the Mission Deputa-

tion of 1825. It is an interesting and important fact that while the fissures about the northeast end of Kilauea are *concentric* with the outline of the crater (Kilauea-iki being included with it), those at the south end are nearly all *longitudinal*, or in the direction of the longer diameter, southwestward. Moreover, as is well known, they extend on for twelve to fifteen miles to the southwest. They are very numerous, more so than is shown on any map or recorded in any description; and some are very deep in places, giving off hot air, steam and sulphurous acid fumes in great volume. While some of them date from 1868, and others from 1886,* still others existed back of all records.

The subsidence that has gone on over this southwestern fissured area has not left any satisfactory evidence of its amount. We know only, that (as the Government map teaches) the surface is about 280 feet below the level of the Volcano House and 395 below that of the Uwekahuna station.

14. *Volcanic sand, stones and scoria, covering all the borders of Kilauea, from an eruption about the year* 1789.—The account of the eruption of 1789, gathered from the natives by the Rev. I. Dibble and published in his "History of the Sandwich Islands"† (1843), mentions that for two nights there were eruptions with ejections of "stones and cinders;" soon followed the rising of a dense, dark cloud from the crater, with thundering and lightning, and then "an immense volume of sand and cinders which were thrown to a great height, and came down in a destructive shower for many miles around."

The "sand and cinders" of this eruption (the latter usually called on the island *pumice*,‡ on account of its extreme lightness, and first mentioned by Ellis, who says "light as a sponge") are well known to cover an area of "many miles" to the southwest of the crater; but the accounts of the region have said nothing about the stones until the publication of Professor C. H. Hitchcock in Science of February last, after his visit to the crater in the summer of 1886. He there reports that:

"Standing at Keanakakoi, one sees to the southwest and south a stretch of volcanic sand and débris fully equal in dimensions to Kilauea itself. On examining more closely the material called 'gravel' on the map, it was seen to consist of material

* Mr. Emerson distinguishes the two sets in his paper in the last volume of this Journal. An exact mapping and numbering of all the fissures, as well as determination of levels, about the Kilauea border would be a very important step toward a correct reading of the future history.

† The facts which Mr. Dibble publishes are cited in my Expl. Exped. Report, on page 183.

‡ Pumice is the scoria of a trachytic or some orthoclase-bearing lava, with the vesicles linear.

ejected from the volcano, and numerous lava-bombs were picked up. Ashes also cover the country to the south and southwest over the Kau desert for several miles."

But it is still not appreciated that Mr. Dibble's words "many miles around" are true if made to include the whole circuit of Kilauea, even the vicinity of the Volcano House, and that the projection of stones preceded that of the light scoria ("pumice"), as Mr. Dibble's account says; yet was itself preceded by a great shower of volcanic ashes or sand. The facts show, moreover, that the stones are in great numbers and of large size to the west and northwest of the crater. The deposit has its maximum thickness over a large area south and southwest of the crater, where it is twenty-five to thirty feet thick and extends ten miles or more away. It is well exposed to view along the fissures. The lower twenty to twenty-five feet of the deposit consist of yellowish brown beds of tufa, the material very fine volcanic sand and hardly consolidated. Above the tufa are two to three feet of a coarse conglomerate consisting chiefly of stones; and above this stratum, a bed twelve to sixteen inches thick of closely packed brownish sponge-like scoria ("pumice"), in pieces half an inch across to two or three inches.

This sponge-like scoria contains the least possible amount of solid matter, being about ninety-eight and one-third per cent air, the rest glass; for the small round cells have no walls except a few slender threads, and it is about as light as a dry sponge. On account of its lightness it is easily carried off by winds as well as the sleepiest of waters, and hence the bed is often left in patches.

The ejected stones vary in size up to several cubic feet. Those of one to two cubic feet are common, many are 20 to 30, and one seen on the west side measured 100 cubic feet and must have weighed over eight tons. Part are ordinary volcanic scoria; but the most of them consist of the more solid basalt sparingly vesicular; and many of the larger are of a light-gray kind very slightly vesicular or hardly at all so, only slightly chrysolitic, and frequently having on the worn exterior a faint banded appearance from alternating variations in compactness of texture. Another kind varies in color from faintly reddish to gray, is more or less vesicular, and contains a large amount of chrysolite—suggesting the nature of a bomb, though not having an exterior shell.*

Going from the southwest border northward and approaching the highest point on the west side, the Uwekahuna station of the survey, the deposit becomes thinner, but retains well its

* The rocks collected on Hawaii have not yet arrived and hence only general descriptions are here given.

characteristics. North of this station the thickness becomes ten feet and less. At the Volcano House it is six feet or more. It may be seen in front of the house at the first descent, where it includes, at bottom, a bed of pebbles; upon this, six to eight inches of the spongy scoria ("pumice"); then another pebbly layer and some fine tufa. It occurs also just north of the Volcano House garden and may be found in traces elsewhere about the north border.

From the south border of the crater the formation extends around by the east side not only to Keanakakoi,* but to the Kilauea-iki depression, thinning northward as on the west side, but having the same characteristics, as observed in the spongy scoria, the great numbers of large stones and the kinds of rock constituting them. But the stones, though many and large, are of somewhat less size than to the west and southwest, and the "pumice" to the northward on this windward side of the crater is in thin widely scattered patches. The tongue of land extending from that side toward the south end of Halema'uma'u, with the words over it on the map "gravel and boulders," owes its gravel and many bowlders to the same source, as Professor Hitchcock implies. The low plain between Kilauea-iki and Kilauea fails of it; but this is owing to recent lava out-flows over the surface. The deep soil and earth farther east over a region crossed by the north and south carriage road by which we made the ascent to the crater, bearing tree-ferns, etc., in luxuriance, is probably an eastern portion of the tufa formation.

The greatness and violence of the eruption cannot be doubted. Its distribution all around Kilauea seems to show that the whole bottom of the pit was in action; yet the southern, as usual, most intensely so. The heavy compact rock of the stones and the size of many of them indicate that the more deep-seated rocks along the conduit of the volcano were torn off by the furiously ascending lavas. It was a *projectile* eruption of Kilauea such as has not been known in more recent times.

I looked along the walls of Kilauea to ascertain whether there was evidence of earlier eruptions of the kind, but found

* The name *Keanakakoi* or Keana-ka-koi, applied on the Hawaiian Government map to the small crater east of the southern half of Kilauea, signifies, as I was informed by an intelligent native, the *chipping-stone pit*, and refers to the fact that formerly a very compact grayish lava was obtained at its bottom and used there for the manufacture of stone implements. No such stone or manufacture has ever existed at Kilauea-iki. This appears to settle the question as to the correct application of the latter name raised by Mr. Brigham. The crater has now a bottom of very smooth recent lava, which our guide stated had been ejected 8 or 10 years back; which suggests that the ejection may have occurred at the time of the eruption of 1879.

no such beds of tufa or conglomerate, and no tufa or sand beds of any kind intervening between the beds of lava constituting them. There are fresh-looking lava-streams over the slopes of Kilauea southwest of the crater, but none appeared along the route to Punaluu of more recent date than the cinder deposit.

15. *The aa lava streams.* — The *aa* areas, looking like ploughed-up lava streams on a majestic scale, occur in the course of outflows of both Kilauea and Mount Loa, and a small area of the kind now exists (see map) in the floor of Kilauea. Several of them were seen on the way up from Keauhou to Kilauea; one about ten miles from Kilauea in Kapapala, near the road to Punaluu, three near Punaluu on the southern border of Hawaii, and one on the lava stream of 1881, within six miles of Hilo. The coarsest and most characteristic of them are those near Punaluu; and that near Hilo has special interest. In crossing Hawaii in 1840 I was over others between Punaluu and Kaulanamauna. My new study of them has led me to a change of opinion as to their mode of origin and to an explanation not yet on record. The description which follows will give others an opportunity to speculate about them.

An *aa* or *arate* lava stream consists of detached masses of lava, as far as is visible from the outside. The masses are of

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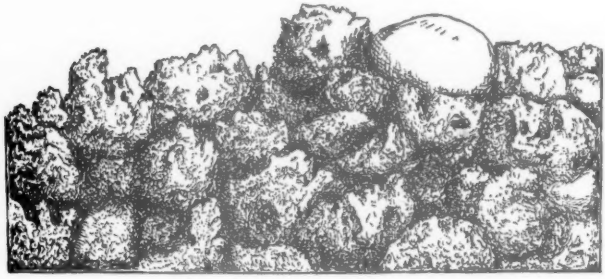


very irregular shapes, and confusedly piled up to nearly a common level, although covering often areas many miles long and half a mile to a mile or more wide. The size of the masses in the coarser kind varies from a few inches across to several yards. The rock constituting the body of the mass is the ordinary solid lava, usually little vesiculated, not the scoriaceous; but the exterior surface is roughly cavernous and horridly jagged, with projections often a foot or more long that are bristled all over with points and angles. In some cases ragged spaces ex-

tend along planes through the large masses, like those of the exterior. But in these as in other parts, it is evident that the agency was tearing and up-ploughing, and cavity-making in its action, and not vesiculating. At one place great slab-like masses of very compact rock, 20 feet or more long, stood vertically together, each about 8 feet high and 3 to 10 inches thick, with a curving over at top, somewhat like gigantic shavings. Ellis, in the "Journal" of the Hawaiian tour of the Mission deputation in 1825, appears to describe similar occurrences over the *aa* fields in the following words:

"Slabs of lava from 9 to 12 inches thick and from 4 to 20 or 30 feet in diameter, were frequently piled up edgewise or stood leaning against several others in a similar manner. Some of them were 6, 10, or 12 feet above the general surface."

These piles of jagged rocks have usually a height of 25 to 40 feet above the level of the adjoining smooth-surfaced stream, owing this height evidently to the large spaces among the blocks.

The above figure represents the features of such a stream. The title of such piles of blocks to the name of a stream would not be admitted were it not proved that they are formed during the progress of a lava-flow; that a lava-stream may change from the smooth-flowing or (pahoehoe) condition to the *aa*, and back again to the smooth-flowing; and that the same vent may give out at one and the same time, a smooth-flowing stream in one direction, and an *aa* stream in another. The Mt. Loa stream of 1880–'81, is mostly a smooth-surfaced stream; but over part of it, within six miles of Hilo (where I went under the guidance of Rev. E. P. Baker, a close student of the Hawaiian volcanoes), the pahoehoe stream changed for a few hundred yards to *aa*, with evidences of transition between them. Further, Mr. Furneaux, an artist, informed me, in his studio at Honolulu, that he was at the head of the flow of 1880, on Mauna Loa, when it was in progress; that one of the three streams which was then flowing from the vent—that going southeastward—was of the *aa* kind, while the other two were smooth-flowing or pahoehoe; that he saw the *aa* stream very gradually advancing, the sides apparently motionless, but about the front, now and then a block tumbling down from above; and the blocks toward the foot at intervals making a shove onward, and rather gaining on the bottom portion where there was impeding friction; and he noticed a red heat between some of the blocks in the front portion. He had in his studio a painting of the scene.

In some *aa* streams, however--probably the thinner streams—the masses are much smaller and more scoria-like than above

described; and these graduate into broken scoriaceous lava-flows.

In two of the *aa* streams near Punaluu the lava is but slightly chrysolitic; in a third somewhat more recent stream, situated not a mile farther west, the lava is very abundantly chrysolitic. All the facts appear to show that there is no connection between kind of rock and kind of flow.

16. *The enormous bomb-like masses of some aa streams.*—The bombs, as they might be called, of the *aa* streams are, inside and out, in striking contrast with the other masses. Many of them occur in the Kapapala stream, and also in those near Punaluu. They are smoothish exteriorly, more or less rounded and bowlder-like; and they vary in size from a mean diameter of a few inches to ten feet and more. One of them is represented in the *aa* picture at the top to the right (p. 362).

Some of these bombs consist outside of a crust, four to six inches thick, of hard grayish, slightly vesicular basalt, and *inside* of fragments of reddish or grayish scoria, the shell being packed full of the scoria fragments. In others similar, the scoria was partly rolled up. Some of them consisted of concentric shells, hard and scoriaceous shells alternating with one another. One had a nucleus of scoria 18 inches in diameter; and around this, successively, a stoney shell of 3 inches; a scoriaceous layer of 1 to 2 inches; a stoney shell of 4 to 5 inches, and then, outside, a rough lava shell 6 inches thick. One of large size, broken open on one side, had had its inside filling of scoria worked out by the natives, and so made into a small cave.

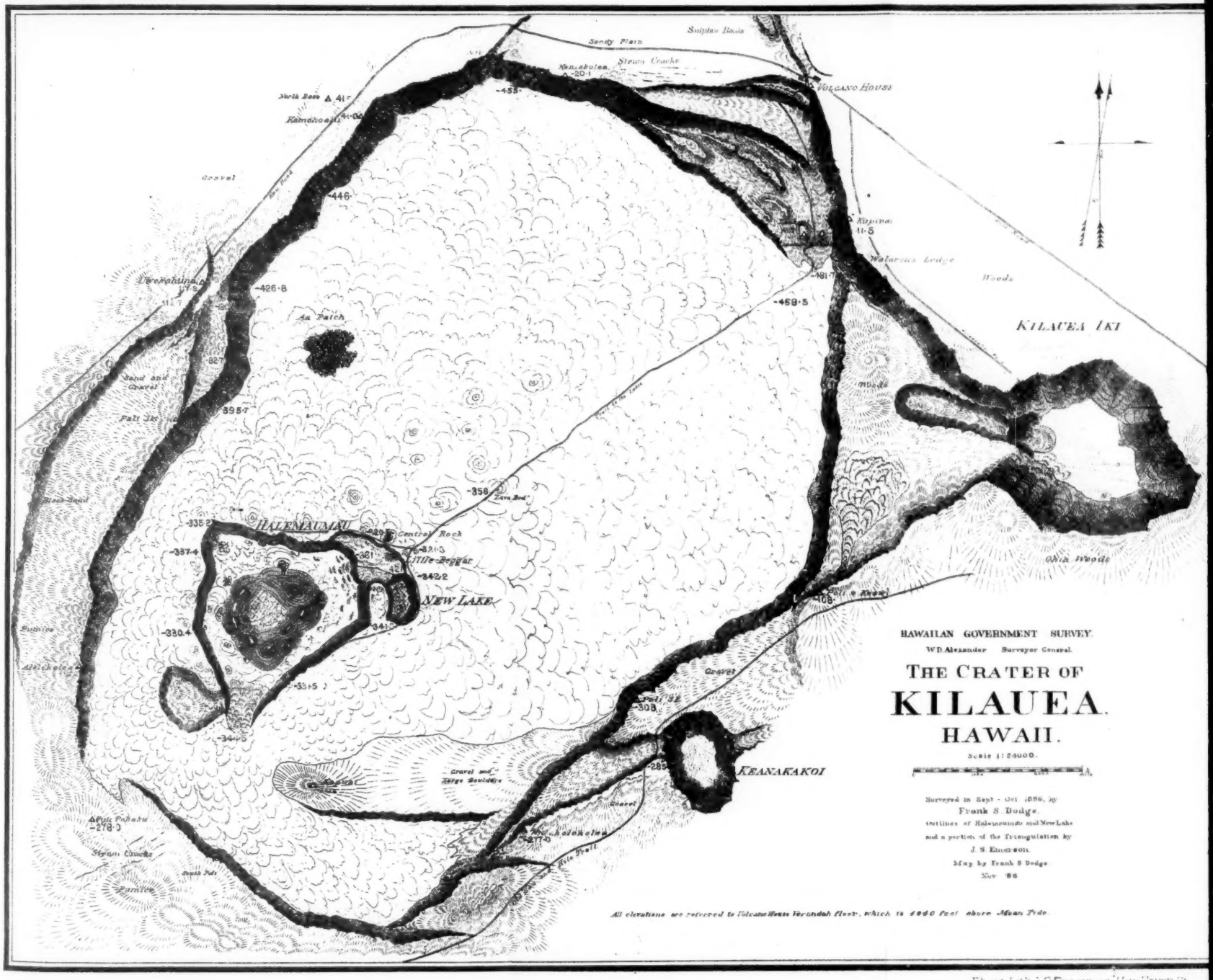
A common size is three to five feet in diameter: but one enormous bomb, in the *aa* field west of Punaluu, measured $24 \times 12 \times 9$ feet in its extreme dimensions, and contained at least 1,000 cubic feet. Enough of its hard outer shell was pealed off to ascertain that the second layer was much vesicular or scoriaceous, and the next layer inside, hard basalt again.

These bombs lie in the midst of the other blocks of the *aa* stream, proving that all had a common origin, and *that they are not projected bombs*, and hence, properly, not bombs at all.*

The further discussion of the phenomena of Kilauea is left for the "Summary and Conclusions."

[To be continued.]

* The word *a-a* is pronounced as if written *ah-ah*, the vowels in all Hawaiian words having the Italian sounds; *au* has the sound of *ow* in English. Kilauea has an accent on the *e*, and Haleakala on the *a* before the *k*. *Pahoehoe* means smooth and shining, and its use is not confined to lava.


Sulphur Banks
Sandy Plain
Steam Cracks
Kau-ahoiea
Volcano House
North Base
Kamakaoia
Gravel
Kapuna
Halemaumau Lodge
Woods
KILAUEA IKI
Pele Pahoehoe
Aa Patch
Sand and Gravel
Pali Ite
Black Sand
HALEMAUMAU
Central Rock
Little Beggar
NEW LAKE
Pumice
Aa Rock
Gravel and Large Boulders
KEANAKAKOI
Pali Pahoehoe
Steam Cracks
Pumice
Ohia Woods
HAWAIIAN GOVERNMENT SURVEY.
W.D. Alexander Surveyor General.
THE CRATER OF
KILAUEA.
HAWAII.
Scale 1:24000.
Surveyed in Sept - Oct 1886, by
Frank S. Dodge.
outlines of Halemaumau and New Lake
and a portion of the Triangulation by
J. S. Emerson.
Map by Frank S Dodge
Nov '86
All elevations are referred to Volcano House Verandah Floor, which is 4040 feet above Mean Tide.

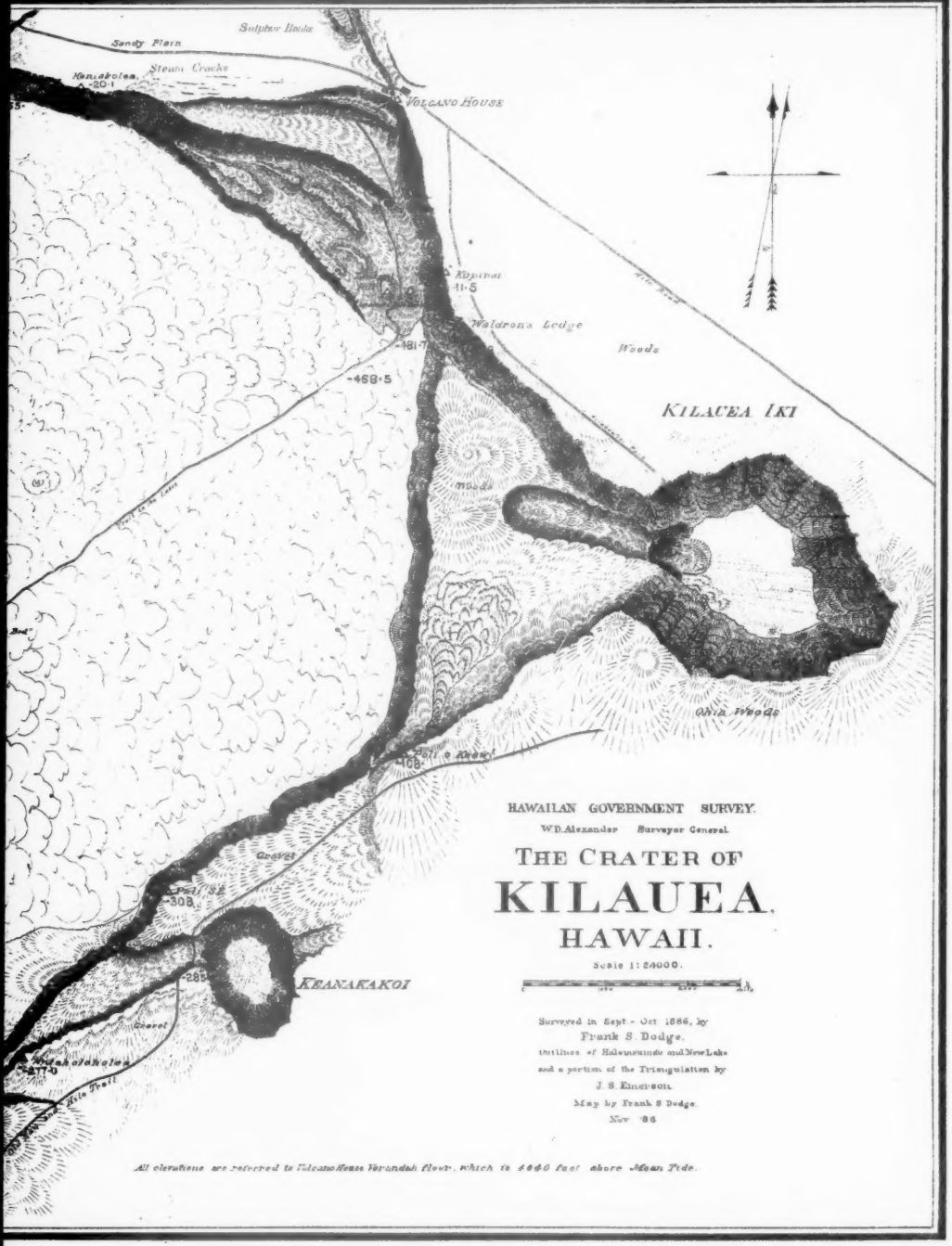



Photo Lith. J.S. Punnerson, New Haven, Ct.

North end of the Halema'uma'u basin and of the debris-cone within it; and above the west wall of the basin, the walls of Kilauea and the dome, Mt. Loa.

LAVA FLOOR OF KILAUEA.

## Art. XXXIX.—*Is there a Huronian Group?* by R. D. Irving.

[Continued from page 263.]

VI. North of the northern limit of the Animiké beds, slaty and schistose rocks form a belt which extends from Vermillion Lake in an easterly and north of east direction to the national boundary line in the vicinity of Knife and Saganaga lakes, a distance of some 60 miles. To the west of Vermillion Lake this belt has been traced for some miles, but is soon lost underneath the heavy glacial accumulations of that region. To the north the schists become involved with granitic and gneissic rocks. A similar area of granite and gneiss bounds the schistose belt on the south, over much of the distance, and here also are seen again the intricate intersections of the schistose rocks by the granite. After reaching a point some thirty miles east of Vermillion Lake, however, the great flat-lying mass of gabbro which lies at the base of the Keweenaw Series of that region overlaps and conceals this granite, the overlap extending over to the schistose belt itself. Another granite area lies directly athwart the course of the schists in the vicinity of Saganaga Lake, although a portion of the schist belt apparently continues farther to the northeastward into Canada along the northwestern side of this granite.

Folding and the production of a schistose structure by lateral pressure seem to have been pushed to the very last extreme among the rocks of this slate and schist belt, the dips within which are generally close to vertical, although here and there among some of the fragmental rocks of the belt, close crumplings may be traced with their sharp anticlinal and synclinal bends. The secondary schistose structure, with its accompanying metasomatic changes has been developed to the highest degree among the rocks of eruptive as well as among those of sedimentary origin. The common structural directions of all the rocks of the belt, as to both strike and dip and the generally prevailing schistose structure, suggest at first the conclusion that all of the schists of the belt are part of one formation; or, if of two formations, that the distinction between the two is no longer recognizable.

A closer study, however, serves to render such a conclusion less evident; and shows that we have among the rocks of the belt two types, in one of which the crystalline structure is complete, and in which there is little or none of an original fragmental texture, while in the other the fragmental texture is still distinct and the alteration has progressed to a smaller degree. Associated with the latter, slaty rather than schistose,

rocks are found great developments of jaspery and cherty ferruginous schists, whose identity as to nature and origin with the ferruginous schists of the iron-bearing formations of the south shore of Lake Superior, and of the Animiké formation of the north shore, seems complete. This identity, taken together with the close similarity of some of the fragmental rocks of the Vermillion Lake band to the fragmental rocks of the Animiké and of the south shore iron-bearing formations, and with the further similarity that obtains between the more distinctly crystalline schists of the Vermillion Lake band and those of the older or gneissic formation of the south shore of Lake Superior, suggests to us that we have here again to do with a separation into an older and a newer schistose formation. This suggestion is deepened into conviction when we further consider the fact that the supposed older one of the two groups of schists in the Vermillion Lake belt is intricately penetrated by the granites of the great areas north and south of the belt, while the same granites, where they come in contact with the supposed newer schists, have yielded to them a profusion of fragmental material, among which fragments are many derived from the supposed older schists themselves.

The appearance is, then, that the conditions obtaining in the Vermillion Lake belt are analogous to those which present themselves in the Menominee region, already briefly described, with the difference that the folding and schistose structure due to lateral pressure have been pushed to an extreme far greater in the former region.

VII. The several regions thus considered furnish us then with a graded series as to the structural relations of the older and newer rocks in each case. The *Animiké rocks* lie upon the older formation with only a slight inclination, and without folds. The *Penokee iron-bearing series*, though still unfolded, lies with a steep northern dip against a wall of the older granite-invaded schists. Next in order comes the case of the unconformity on the north shore of Lake Huron, where the *typical Huronian series* is gently bowed, but is without true schistose structure. In the case of the unconformity of the *Marquette region*, the upper group is crumpled between walls of the older schists, at times even having the folds overturned, with frequent developments of slaty cleavage; but still having the folds in the main open, and presenting a true schistose structure only rarely. In all of these cases—least distinctly of course in the last case—the distinctness of the two formations concerned is to be made out in part from the visibly discordant positions of the rocks of the two series. But when we proceed to the next case on the list, that of the *Menominee region*, such discordances are no

longer distinct, the close folding having brought the stratiform members of both groups to too great a uniformity of inclination. Finally, in the *Vermillion Lake region* the extreme pressure to which the rocks have been subjected has not only brought about a general community of inclination between the rocks of the two groups, but has developed in the lower group, and among the eruptives of the upper group, so complete a schistose structure as to render the separation of the two series often exceedingly difficult. Nevertheless, that the two groups are there actually represented the facts above presented seem to me clearly to demonstrate; while such a state of affairs as there obtains is certainly no theoretical impossibility on the hypothesis that these schists include two entirely distinct series of rocks. Imagine, for instance, the region of the Alps of southern Europe planed off by denudation to a level surface. Here Archæan crystalline schists and various fossiliferous formations are intricately folded together; and the appearances resulting from such a planing off would not be so far different from those obtaining in those portions of the Lake Superior region, where Archæan schists and newer detrital rocks are folded together, save that the newer formations would now be fossiliferous.

There must be cases, however, where it will long remain very difficult, if not impossible, to separate the Huronian from older schists, or to determine if any Huronian be present. This I suspect will be the case with some of the Canadian belts north and northeast of Lake Superior, which have been called Huronian. A large part of the schists of these belts are plainly *not* Huronian; but it remains to be seen whether any of the belts contain any true Huronian, and whether there may not be some further division possible of the pre-Huronian schists; a view maintained vigorously by Mr. Lawson, of the Canadian Survey. As to this I do not care to express, now, any very definite opinion. However, it seems plain that no such facts as those here presented to substantiate the complete separation that obtains between the Huronian and the pre-Huronian rocks have been yet advanced to establish a separability of the latter rocks themselves.

Throughout the region then which stretches from the north shore of Lake Huron to the Mississippi River, we find evidence of the existence of this same discordance between the Huronian, and the older basement rocks—a discordance due to one and the same orographic disturbance. Bearing in mind the discordance between the Huronian and the overlying Keweenaw series, and that between the Keweenaw series and Potsdam sandstone, we reach the conclusion that throughout this great region the following succession obtains, in ascending order:

(1.) The great *basement complex*, of crystalline schists, gneiss and granite, as to whose further divisibility or non-divisibility no opinion is now expressed. Above this basement, but separated from it by a great structural hiatus, follows:

(2). The *Huronian Group*, mainly of detrital rocks; which is followed in turn, but after a severe structural break, by

(3). The *Keweenaw Group* of interleaved detrital and eruptive beds, which is also entitled to the group rank. Finally, upon the eroded edges of this series follows

(4). The *Potsdam* or Upper Cambrian sandstone.

VIII. Thus far I have directed your attention only to the region between the north shore of Lake Huron and the upper Mississippi River—a region which we may conveniently call the Lake Superior Geological Province. But geologists have often made correlations of the rocks of other and remote regions with the type Huronian, and this not only for various portions of North America, but of other continents as well. Such correlations have been made chiefly, often exclusively, on the basis of a lithological similarity to the original or type series, and should therefore be received with the very gravest doubt; but to make the matter worse the lithological comparison has been with a standard *which does not exist in the type area*, and which, where anything like it does appear in the neighboring regions, is plainly pre-Huronian, i. e., is part of the great basement complex.

Correlations with the type Huronian may be received with more confidence perhaps, if for regions not too remote from the type area, when based on a parallelization of unconformities above and below the type series. Such unconformities are plainly the result of an intervention of mountain-making disturbances whose influences must generally have been widespread. Thus a succession similar to that of the Lake Superior region, and with similar discordances, obtains beneath the equivalent of the Potsdam sandstone in the Colorado Cañon; and probably also in Central Texas. In Newfoundland again, lying unconformably beneath the lowest known fossiliferous Cambrian horizons, are two mutually discordant series, the upper one of which is detrital, and the lower crystalline and gneissic. The use of such a method of correlation, however, is not advocated as being of value in inter-continental comparisons, or even in inter-regional ones, when the basins compared are too remote from one another; though it may be said that it could hardly give much less satisfactory results than have at times been yielded by the paleontological method.

But while we cannot with confidence correlate the Huronian or Keweenawan of the Lake Superior region with any particu-

lar pre-Cambrian series outside of that geological province, we can confidently enough, I think, correlate the geological interval which holds these Lake Superior formations with that which intervenes the world over between the Cambrian and the great basement of genuine crystalline rocks, and which in several regions includes great groups—sometimes one, sometimes more—of fragmental sedimentary strata. The progress of geological discovery has been a downward one, and we may look for the discovery of more fragmental groups than these, and, I think, for the discovery of new faunæ In any case, whether our discoveries in this direction are at an end or not, some term—at least provisional in its application—covering the great interval between the Cambrian and the Archæan, and the clastic groups which have been or may be found lying in this interval, would not only be a convenient addition to geological nomenclature, but would express a great truth which the taxonomical system now generally in use entirely ignores.

IX. In the foregoing pages I have shown that the Huronian series is traceable throughout the Lake Superior Province, and have presented a summary of facts which, as it seems to me, establish its clastic and sedimentary nature, its great volume, and its structural and chronological separateness from all other rock groups. I may now turn back once more to the quotation which serves as the text of this essay and see how far the definition of a group there given is satisfied in the case of the Huronian series; and, if there is any failure to satisfy this definition in full, whether such failure should be allowed to exclude this immense volume of strata from the group column, and to compel the ignoring in geological chronology of the immense lapse of time to which it must correspond.

Analyzing the definition referred to, we find that it includes the following distinct requirements; whose order, however, for convenience of reference, I change from that given in the quotation itself:—(1) All clastic formations, known to be such, must be included within some group or other; (2) the group is made up of sedimentary (mainly clastic) strata; (3) it includes subordinate members genetically separate from one another; that is, is made up of *formations;* (4) it has a volume comparable with that of other recognized groups, such as the Cambrian, Silurian, Devonian, etc.; (5) it is presumably world-wide in distribution, being recognizable in various countries; (6) it is defined mainly by paleontology, or "is admitted by all geologists for motives in part arbitrary."

The first of these conditions plainly compels us to place the Huronian in some one of the already recognized groups, or to make a new group for it, of which alternatives it has already

been seen that we can take only the latter. It has also already been abundantly shown that the second, third and fourth requirements are fully met in the case of the Huronian. As to the fifth, it is to be said that a thickness of 18,000 feet of sedimentary strata, extending, as the Lake Superior Huronian does—or did before erosion—over an area of 800 by 400 miles, and in all probability over an area as large again as this, certainly has "presumptively" its exact chronological equivalent in other geological basins. That it has been recognized in other countries cannot be said. Rocks of fragmental origin which are with sufficient probability, in part at least, the equivalents of the type Huronian have been recognized in different countries, and on different continents, between the Cambrian base and the Archæan schists; but all that we can now say with regard to them is that they belong to the same general geological interval with the Lake Superior Huronian. As to the sixth or final characteristic, that the group is defined by paleontology, it is to be said that the Huronian is so only so far as it is proved to be pre-Cambrian by the fact that it antedates by an immense interval of time rocks holding Cambrian fossils. It has so far yielded no recognizable fauna of its own.

Thus the only departure from the definition lies in the fact that the Huronian, while plainly in all other respects a group, is not to be correlated with any particular pre-Cambrian or other rocks by a comparison of fossils. The writer himself is not among those who accept paleontological correlations in the extreme way in which they have frequently been presented to us in the books; indeed, he is disposed to agree with those others who think that, while there has been a general similarity in development in different basins of rock growth, or even in different continents, the similarly named groups of these different basins and continents have hardly been always so exactly correspondent or even homotaxial as has generally been supposed. It would seem that the author of the quotation referred to held also somewhat the same views from the fact that he speaks of the ordinarily accepted groups as arbitrarily determined, in part at least. But, waiving such considerations, it would seem that one need hardly do more than ask the question—whether the great thickness of rocks in the Huronian series, not to speak of that included within the Keweenawan, is to be ignored in geological chronology merely because its exact geological equivalents in other regions are not strictly recognizable as such—to receive a negative answer.

The Huronian then is a true sedimentary group in origin, in volume, in chronological distinctness from other groups above and below it. It is not only *comparable*, as to volume, with the ordinarily recognized rock groups, it *exceeds* most of them;

besides which it is separated from adjacent rocks by tremendous unconformities, representative of immense lapses of time, while in many cases the later fossiliferous groups are divided from one another by no sharp structural or even paleontological line. Now similar arguments would establish the group rank also of the Keweenaw series. These two groups represent a great lapse of time hitherto ignored. They belong to that great gap—which they only partially fill—lying between the Cambrian and the Archæan, as do also other rock groups in other portions of the world.

As now generally accepted and presented in the books, the geological column makes no provision whatever for these great intermediate groups of strata; nor is there any uniformity of practice as to their classification among those geologists who have written upon them. Even among those who believe in its complete structural separateness from the upper Cambrian strata the Keweenaw series has been classified now as the upper portion of the Archæan, now as the lower portion of the Cambrian. The Huronian when first recognized by the Canadian Survey was put in the Cambrian; later the same survey threw it into the Archæan. In the same way the immense succession of rocks which lies below the great unconformity of the depths of the Grand Cañon of the Colorado has been classed now as Cambrian, again as Archæan. But all of these groups are plainly wholly separate in point of time of production from both the Cambrian above and the Archæan below, each of them being fully entitled to a classificatory value equal to that of Cambrian, Silurian, etc. It seems evident, then, that they should receive admission, as entirely separate groups, to the geological column. But their admission to this column appears to involve a difficulty, and also a further important modification of the column. As has already been fully admitted, we cannot speak, certainly in the present stage of the science, of Huronian rocks in portions of the world remote from the Lake Superior Province. In other words, we cannot correlate directly with the Huronian any pre-Cambrian fragmentals elsewhere found, since such fragmentals might, so far as we are able to determine, be rather the equivalents of the Keweenawan or of some series belonging in the gap above the Keweenawan, in that below it, or again in that below the Huronian. We must, therefore, in constructing our column, in some way indicate that these groups have individually a recognizable extent which is as yet only local. But plainly some term is necessary to cover all of these groups collectively; in other words, all of that great gap which lies between the base of the Cambrian and the summit of the Archæan gneissic and schistose basement. This name cannot be one of the group rank, since it

must cover two or more groups itself; it must be of the same rank with Paleozoic, Mesozoic, and Cenozoic.

To follow out the idea that is contained in these three terms, the new term should have some reference to the life-conditions of these early times. That life existed during the accumulation of the pre-Cambrian fragmentals seems to me to admit of no question. For proof of this I will not appeal to the high development of the first Cambrian fauna, nor to the fossil or fossil-like forms which have been found in the quartzites of southwestern Minnesota, in the Keweenaw series of Lake Superior, in the pre-Cambrian quartzites of Newfoundland, and in the Grand-Cañon series of Arizona; nor will I advance the usual arguments in favor of an Archæan life. I will only bring forward the wide-spread occurrence, within the Huronian of the Lake-Superior province, of two materials whose organic origin would seem to be beyond question. I refer to the carbonaceous shales and to the iron carbonates—or derivatives from iron carbonates—often associated with them. It is somewhat singular that these materials have been largely ignored in the various discussions that have taken place during many years past as to the existence or non-existence of life in pre-Cambrian times. It is true that the iron oxide accumulations of the Archæan have been used in this connection very often; but a doubt always remains as to whether these may not possibly be of chemical origin. In the case of the iron carbonates associated with carbonaceous shales in the Huronian, however, it does not seem that any such question can arise, since, as I have tried to show elsewhere, this association is one for which we can imagine no possible explanation other than that generally given to account for the association of similar materials at various higher geological horizons, notably the coal measures. Again, the carbonaceous shales themselves, taken alone, furnish an equally strong argument; for, while a doubt as to an organic origin for the graphite masses of the Archæan may perhaps be entertained, no such doubt can be admitted with regard to these shales, the carbonaceous matter of which is mingled with argillaceous fragmental material, whose accumulation in water by the ordinary processes of sedimentation must be taken as certain. Moreover, this carbonaceous matter, in the case of those shales which are separate from the iron carbonate accumulations, as well as in those that are associated with this carbonate, seems often to be distinctly *organic matter*, that is to say, is hydro-carbonaceous. We need not question, then, the existence of life during the accumulation of part if not all of the pre-Cambrian fragmentals. The *nature* of the life that then existed, however, we know practically nothing about, since, with the exception of those few doubtful forms already re-

ferred to, no fossils whatever have been met with in these ancient formations. The only things, then, that we can affirm with regard to the life of these early periods are, that it existed, and that we know nothing of its nature. I have already indicated my anticipation of the discovery of the remains of faunæ earlier than any of those with which we are now acquainted; though it may be that those are correct who imagine that no such remains will ever be brought to light, because of the probability that the earlier forms of life were unprovided with hard parts.

The general term to be used to cover the great pre-Cambrian interval should then express the existence of this early life, and our present ignorance with regard to its nature. During the year and a half that such an addition to geological nomenclature has been under discussion between myself and several of my fellow-geologists, many terms have been proposed and discussed. Some of these have been rejected because, though sufficiently appropriate, they have already been too generally used in other connections. Others again seemed inadmissible because, while expressing well the idea to be presented, they were made up of derivatives from the Greek not ordinarily met with in the English language, and were too cumbersome and pedantic in sound. Others again, like *Proterozoic* (*πρότερος*, *earlier*), suggested by Mr. Emmons, while simple and made from a Greek word of not too uncommon use, seemed to fail in covering the ground sufficiently. I have therefore been disposed to return to a term early proposed by Professor T. C. Chamberlin, to whom indeed is to be assigned the first suggestion of the use of a single name to cover all of the pre-Cambrian fragmentals. I would advocate therefore, the use of the term *Agnotozoic* (*ἄγνωτος*, *unknown*; *ζωή*, *life*), to cover all of the geological interval lying between the base of the Cambrian and the summit of the Archæan crystallines. This proposal I make with a good deal of hesitation, and only after consultation with several of my fellow geologists. Not that I have any question as to the need of such a term, nor as to the hitherto too much ignored truth which I conceive it to express; my hesitation arises simply from the feeling that so important an addition to geological nomenclature should hardly be attempted by any single individual.

I ought not to conclude without alluding to one objection to the proposed new term—or indeed to any term designed to have the same scope—brought forward by one of my colleagues; this is, that while the upper limit of the proposed Agnotozoic is clearly enough defined by the basal Cambrian fauna above, the lower limit is not similarly defined, and that if we accept the view of some geologists that metamorphism

has progressed upwardly to irregular distances among the early fragmentals, we should be calling fragmental rocks of one region Agnotozoic, while the crystalline schists, representative of these in other regions, would be classed as Archæan. In reply to this objection I should say, in the first place, that a number of the geologists who of later years have concerned themselves with the early formations have been tending more and more to the conclusion that there is always a reasonably easy line of demarkation between the true Archæan crystallines and the overlying fragmentals. My own experience has led me strongly toward such a view. But even if this be not the case, it is to be said that the lower limit of the proposed Agnotozoic would on the whole be but little more arbitrary in any universal application than are those lines generally accepted as established paleontologically. These paleontological boundaries have generally been established in the first place for a restricted region, and their application to other geological basins, and particularly to distant continents, has always been in a measure an arbitrary one. It should be understood distinctly that the term is proposed to cover, not any non-fossiliferous formations lying beneath the Cambrian—since so far as they are in complete conformity with the overlying Cambrian they *may* be merely its downward extensions—but such non-fossiliferous and distinctly fragmental and sedimentary rocks as are separated from the Cambrian base by a genuine wide-spread unconformity; that is, by a structural break indicative of an enormous lapse of unrecorded time.

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ART. XL.—*Rounded Bowlders at high altitudes along some Appalachian Rivers;* by I. C. WHITE.

IN a paper read at the Minneapolis meeting of the American Association the writer described some deposits along the Monongahela and Teazes valleys in West Virginia, that seemed to furnish strong confirmation of Professor Wright's hypothetical ice dam. Since the preparation of that paper many other facts bearing on the question at issue have come under my observation, and they are here placed on record with a view of assisting those who are making a specialty of surface geology to the correct solution of the problems they involve.

That the terrace deposits along the Monongahela, Allegheny and Ohio valleys were formed during a *submergence* of some kind, will, I think, hardly be questioned by any geologist thoroughly familiar with the nature and extent of the deposits themselves; for there are numerous localities where the evi-

dence would seem to be conclusive that these valleys had been eroded to near their present depths before the deposition of the rounded bowlders, clay, logs, leaves, and other trash that constitute the deposits. The single fact that they disappear abruptly would seem to be sufficient evidence that they did not originate, as some have supposed, from the detrital matter which the streams left along their banks in the original erosion of these valleys. No one, it seems to me, could question the submergence of the upper Ohio valley in recent geological times, who has carefully examined the deposits in the old, and abandoned Teazes valley, along the C. & O. R. R., through Mason and Cabbell counties, West Virginia. Hence I think the submergence may be considered as established; the only question open being whether this submergence was general, involving a continental movement, submerging the valleys east from the Allegheny Mountains, as well as those west from the same, or whether the submergence of the Ohio and its tributaries was of a local character and accomplished through the agency of the glacial dam which Professor Wright believes existed in the region of Cincinnati. Some of the facts now to be enumerated may be equally well explained on either hypothesis.

About ten miles above the mouth of the Big Sandy River, and on the West Virginia side, a considerable deposit of small water-worn bowlders occurs near the summit of a broad, flat-topped hill, at an elevation of 400 feet above the stream, or not far from 900 above tide. This deposit is interesting from the fact that it is the only one that I was able to find between the point in question and the source of the river, nearly 200 miles above, though the failure may be satisfactorily accounted for by the precipitous character of the bounding valley walls, and the unusually soft and easily disintegrated nature of all the surface rocks; for all along the Big Sandy, even the Pottsville conglomerate becomes rotten, and very readily crumbles into loose sand, which, carried down by the rain, fills up the channel of the river and has thus given name to the stream. It is not assuming too much to state that these rounded bowlders of local coal-measure sandstone could hardly have resisted the elements during the long time since the Big Sandy valley existed at this 400-foot level.

The Guyandotte river puts into the Ohio next above the Big Sandy, and on this stream about 100 miles above its mouth, a large deposit of rounded bowlders was observed on the inner side of one of its curves opposite the mouth of Panther Creek. The bowlders cease at 150 feet above the stream, or about 925 feet above tide, according to levels run by Captain Miller, of the Trans-flat Top Land Company.

The bowlder deposits are found in greatest quantity about

the junction of streams, and consequently at the mouth of Elk River, on the great Kanawha, in the vicinity of Charleston. Vast numbers of them extend to near 250 feet above this river (800 feet above tide), and scattering ones are found up to 390 feet or 945 feet above tide. Here, along with the hard rocks of local origin, we find great numbers that have come from the Blue Ridge in Virginia and North Carolina, nearly 200 miles distant.

The effect of local causes in both forming and preserving these deposits is well illustrated along the great Kanawha, for with a single exception (near the mouth of Paint Creek), no other deposit of bowlders exists between Charleston and the mouth of Gauley river, a distance of 40 miles. At this latter point, however, the quantity of rubbish thrown down seems to have been so great that a considerable thickness of rounded bowlders still exists on a comparatively steep slope up to 150 feet above the river; but here the ascent becomes almost precipitous and the deposit disappears.

On Elk River, two miles above Charleston, an example may be observed very similar to the famous one of Teazes valley, though on a much smaller scale. Here a stream, known as Two-mile, enters Elk, and on following up the same for a distance of two miles, we find one of its branches heading in a narrow valley up against a creek which flows in the opposite direction and enters Elk about five miles above Charleston. The divide between the two streams is almost imperceptible, and it is covered with a deposit of clay and rounded bowlders at an elevation of 175 feet above the level of the Elk, thus proving that an arm of the same passed through this valley during the epoch of submergence. From Major Campbell, of Charleston, to whom I am indebted for the elevation of this old water-way, I learn that another abandoned valley precisely similar to the one at the head of Two-mile, may be seen about ten miles farther up Elk River.

It is a remarkable fact that along the Ohio valley, between Point Pleasant and Rochester, with a single exception, transported bowlders have never been reported above the level of the third terrace, or say an extreme elevation of 100–125 feet above low-water. I have myself examined the hill-slopes at probably 200 different points between the mouth of the big Kanawha and the Beaver 250 miles above, and with the single exception noted, not one water-worn bowlder has been observed above the uppermost of the broad river bottoms. We cannot doubt that they once existed far up these river hills, since, at Pittsburgh, above, and Charleston, below, they occur several hundred feet higher than along the intermediate Ohio. It is very probable that their absence is due to the very steep hill slopes that exist throughout the region in question, thus permit-

ting the few stranded bowlders to be shed into the valleys by subsequent erosion.

All who are familiar with the region about Pittsburgh, and as far down the Ohio as Bellevue, cannot have failed to observe the immense deposits of transported bowlder trash that have accumulated about the junction of the Allegheny and Monongahela rivers. The beautiful valley of East Liberty and Homewood owes its origin to the submergence of this region to such a depth that a branch of the Monongahela once extended across the divide near Homewood, and connected with the Allegheny several miles above the present junction. The extreme elevation of the great bowlder heaps around Pittsburgh is about 300 feet above water level (1,000 feet above tide). At Sewickley the great deposit ends about 160 feet above the river; near the mouth of Beaver it is only 125 above; and still farther down the Ohio the top limit of the deposit declines to 100, and often to not more than 80 feet above low water.

In the vicinity of Sewickley, during the past year, I discovered transported bowlders extending up to nearly 600 feet above the Ohio, or more accurately 1,250 feet above tide. It is true the same observation had previously been made along the Ohio near Sisterville, but this being then the only known instance of water-worn bowlders at such a great elevation, and only a few of them being found, it was considered probable that the Indians had carried them up from the valley for some purpose. They are not abundant at this great elevation in the vicinity of Bellevue and Sewickley, but the farmers report that they plough them up occasionally in every field for about one mile back from the river. None was seen of a diameter greater than 6 inches. From the fact that these few scattering bowlders are confined to the river valley, I still think it very probable that they were carried to these high levels by the Indians. Granitic bowlders of small size have also recently been found near Washington, Pa., at the head of Chartiers Creek, which empties into the Ohio river a short distance below the mouth of the Allegheny. I have seen only a few of these, but Mr. A. J. Montgomery, on whose farm they occur, reports that a large number of them were found in digging a ditch for the natural gas main, a short distance outside of the borough. The elevation of the Chartiers Valley railroad depot is 1,030 feet above tide, and the granitic bowlders picked up near Mr. Montgomery's were about 20 feet higher. This locality is so far (30 miles) from the Ohio Valley that we cannot, with much degree of plausibility, ascribe the presence of the bowlders to Indian transportation, and especially the regular bed of them which Mr. Montgomery saw in the Pipe Line ditch. As the Chartiers Valley is almost a direct (southward) continuation of the Alle-

gheny, it seems probable that these granite bowlders were transported to the head of the Chartiers by the current which set down the Allegheny during the epoch of submergence, having been gathered up by the latter stream where it crossed the terminal moraine below Franklin.

Near the mouths of the Conemaugh, Youghiogheny, and Cheat Rivers, large deposits of rounded bowlders extend up 250–300 above the present water level, but as we ascend any of these streams the bowlder line gradually declines until along the upper reaches of each stream, the deposits fail at 75–100 feet above water level.

Owing to the nature of the topography, and the country rock along the draining streams, the region along the Upper Monongahela has these terrace deposits in better preservation than any other with which the writer is acquainted, and this is especially true of the West Fork branch of that stream. It is along this line that the existence of a great submergence which covered the country with a thick coating of transported material up to a certain level, is most conclusively shown. In the region of Morgantown, on the main Monongahela, these terrace deposits end at about 275 feet above low water, or 1065 feet above tide, while at Fairmount, 26 miles above, there is a vast amount of this terrace material thrown down about the junction of the Valley and West Fork Rivers, and the upper limit of the same is a little over 200 feet above low water, which is here 850 feet above tide.

About 20 miles farther up the river (West Fork), near Shinnston, the upper limit of the terrace material is found at 160 feet above the water, but here the latter has an elevation of about 885 feet above tide.

At Clarksburg, where the river unites with Elk Creek, there is a wide stretch of terrace deposits, and the upper limit is there about 1050 feet above tide, or only 130 feet above low water (920) while at Weston, 40 miles above (by the river), these deposits cease at 70 feet above low water which is there 985 feet above tide. It will thus be observed that the upper limit of the deposits retains a practical horizontality from Morgantown to Weston, a distance of 100 miles, since the upper limit has the same elevation above tide (1045–1065), at every locality.

These deposits consist of rounded bowlders of sandstone, with a large amount of clay, quicksand and other detrital matter. The country rock in this region consists of the soft shales and limestones of the Upper Coal-measures, and hence there are many "low gaps" from the head of one little stream to that of another, especially along the immediate region of the river, and in every case the summits of these divides, where they do not

exceed an elevation of 1050 feet above tide are covered with transported, or terrace material, but where the summits go more than a few feet above that level we find no transported material upon them, but simply the decomposed country rock.

A fine example of one of these bowlder-covered divides may be seen at the mouth of the Youghiogheny River, back of McKeesport, Pa. The "divide" in question is one between the waters of Long Run, which puts into the Youghiogheny, two miles above McKeesport, and that of another little stream which heads up against it, and flows into the Monongahela within the city limits. The divide between these two waterways, although 275 feet above the level of the river, is almost imperceptible in a broad, and bowlder-covered valley through which there is not the slightest doubt that the waters of the Youghiogheny once flowed during the epoch of submergence.

When we cross to the eastern side of the Alleghenies, bowlder beds are also found at high elevations along all the streams which have their sources in the mountains. At Piedmont, on the North Potomac, where water-level is about 910 feet above tide the rounded bowlders cease at 150 feet above the stream, while at Cumberland, 50 miles below, where the river level is 615 feet above tide the rounded bowlders can be traced up to 300 feet above the stream.

That this region along the Potomac has been submerged during recent times, seems fully proven by some facts observed along Patterson's Creek, 8 miles below Cumberland; for here the submergence is attested by the presence of a bed of curious conglomerate, made up of angular and water-worn fragments of local rock (limestone, slate, sandstone, &c.) the cementing material being lime and iron. The stratum is 1–3 feet thick, and the remnants of it encircle the valley of the stream where it is found 10–15 feet above water level. It is reddish colored from iron stains and would seem to correspond quite well with the "Bryn Mawr" conglomerate described by Prof. H. Carvill Lewis, from the vicinity of Philadelphia. It seems to have once covered a considerable area in the Patterson's Creek valley, since Col. Jno. A. Robinson, who first called my attention to the bed, informs me that he has observed fragments of it five miles up the Patterson's Creek valley. The elevation of the B. & O. R. R. station at the mouth of Patterson's Creek is 568 feet above tide, and the level of the conglomerate is 20 feet higher, or 588 feet above tide.

A narrow, synclinal valley of Marcellus slate, bounded on either side by arches (ridges) of Oriskany sandstone, which carry on their slopes the outcrops of the Marcellus or Selinsgrove limestones, furnishes a sufficient reason for the origin of this conglomerate in a submerged valley.

Along the South Potomac, the Shenandoah, the James, and other rivers of Virginia, large deposits of rounded bowlders are found far above where the present streams ever rise, and the similarity of the deposits to those occurring along the rivers west of the Alleghenies is very striking. It is barely possible they have had a common cause in a submergence of continental extent, but at the same time there can be no doubt that the hypothetical "Ice Dam" of Prof. Wright, would satisfactorily account for all the phenomena of surface geology which exist along the rivers west from the Alleghenies.

Submergence, with re-elevation in comparatively recent times, will then give a sufficient explanation for the existence of the elevated bowlder deposits in the vicinity of Washington, D. C., Richmond, Philadelphia, and possibly as far west as Cumberland, but along some of the Appalachian rivers we meet with a class of facts that neither the "Ice Dam" hypothesis of Prof. Wright, nor the (seemingly demonstrated) Atlantic coast submergence will satisfactorily explain. Reference is here made to the bowlder deposits that occur far above the level of the present streams, when we have followed them so near their sources as to be high above the limits of Prof. Wright's "Ice Dam," and also still higher above any evidence of continental submergence. One of these remarkable deposits may be seen on Cheat River, in Tucker County, West Va., a short distance above St. George. The elevation of the river's bed is there about 1500 feet above tide, and yet great deposits of rounded bowlders and other detrital material are found lining the valley in terraces up to 175 feet above the level of the stream. It has occurred to me that possibly during the long cold of the Glacial epoch, the snows may have accumulated to a depth sufficiently great along the Alleghenies to form local slides of considerable extent, which might dam up the streams in their upper reaches where they flow along the slopes of the mountains in narrow gorges, like the Cheat in the vicinity of Rowlesburg, a few miles below where the terrace deposits in question have been noted.

Mr. N. D. Adams, of St. George, and the present editor of the Wheeling Register, informs me that near the county seat of Tucker there is a very high hill bordering the valley of Cheat River, and that circling back around it is an old river channel filled with water-worn stones and other transported trash at a considerable elevation above the level of the river. This, together with the terrace deposits observed by myself above St. George, would seem to prove that the valley of this stream has been submerged in that region within recent geological time, or at least not earlier than the Glacial epoch, and yet I can see no explanation for the submergence in this or other similar

cases except the one suggested above. It is true that the rivers which flowed from the Appalachian plateau after the accumulated snows of the Glacial epoch began to melt away, would vastly exceed in volume any floods with which we are now acquainted, but still they would culminate far below the 175-foot level, and we can scarcely believe that subsequent erosion has deepened the valleys so much as to make up for the difference.

West Va. University, Morgantown, Aug. 1st, 1887.

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ART. XLI.—*Description of an Iron Meteorite from St. Croix Co., Wisconsin;* by DAVENPORT FISHER. (With Plate V.)

THE mass of meteoric iron described in this paper was plowed up three years ago (1884) in a cornfield on the farm of Mrs. Jenette Rattary in Hammond Township, St. Croix County, Wisconsin. (The exact description of the forty acres is:—North $\frac{1}{2}$ of S. W. $\frac{1}{4}$ of Sec. 31, Township 29, Range 17 West.)

It attracted attention from its weight and silvery luster where freshly abraded, and was supposed to contain silver, but its real nature was not suspected, and it lay about the farmyard until last winter. At that time, during the excitement about iron ores in that neighborhood, a speculator chanced to see it and he at once paid fifty dollars for an option on the forty acres to prospect for iron ore. The mass was sent to me for analysis, and on its being reported to be a meteorite was reclaimed by the owner, and it was not until I visited the region in May last, that the facts of its discovery were ascertained.

It was struck by the plow near the surface of the ground, in a field that had been cultivated for corn for several successive years, and the farmer was quite certain that it could not have been there the year before, and its fresh appearance noted later, testifies to the probability of its having recently fallen. It is quite remarkable that it kept so bright during the three years it lay in the farmer's yard. No similar pieces have been seen, nor does this show signs of fracture.

The mass has been considerably disfigured by attempts to chisel off pieces at different points, and one piece was detached and forged into a spike, but this I did not see. When it reached me it weighed 53 pounds (24 K.). It is of irregular shape, as shown in the accompanying cut, engraved from a photograph I had taken when it first reached me.

Its dimensions are 8 by 8 inches across the face and 7 inches through, in the thicker part, but with an average thickness of

4 to 5 inches. The back side, as the view is taken, is nearly flat and pretty uniformly covered with circular pittings. On

this side, it presents the ordinary appearance of most masses of meteoric iron, the surface crust having entirely disappeared. It seems probable that it lay with this surface in contact with the ground during the three years after it was dug up, and the crust disappeared by the ordinary process of weathering. The front side is less regular in shape and shows several large depressions. This surface is largely covered with the fused crust which is heaped up in ridges and shows all the perfections of the lines of flow characteristic of irons which have been picked up immediately after their fall; the only change being a partial oxidation of this film so that it appears in places brown instead of black. This character of the St. Croix meteorite,

independent of the confirmatory evidence afforded by the circumstances of its history, would make it probable that its fall did not precede by many months the date of its discovery.

A careful analysis of the iron was made by the writer and his assistant, Mr. Chas. G. Allmendinger, with the following results:

Sp. gr. $^{1st}7{\cdot}601 - ^{2d}7{\cdot}703$ (Two different pieces).

| | |
|---|---|
| Iron | 89·78 |
| Nickel | 7·655 |
| Cobalt | 1·325 |
| Phosphorus | ·512 |
| Silica | ·562 |
| Carbon | traces |
| Copper | traces |
| Tin | traces |
| | 99·834 |

It contained nodules of troilite, 3 appearing in one section, from 3$^{mm}$ to 12$^{mm}$ in diameter. No other inclosures were detected by me.

I am indebted to Mr. Geo. F. Kunz for sections cut from the mass and polished for etching, and I leave to him the description of the Widmanstätten figures, etc. The meteorite now forms a part of the collection of Yale University at New Haven.

### Note by Mr. George F. Kunz.

When dilute nitric acid is applied to the St. Croix County iron, the Widmanstätten figures quickly appear, but unlike the Glorieta and Staunton meteorites, it could not be etched to any depth, because on long continued application of the acid, the entire surface of the iron rapidly dissolves away, leaving only projecting points of taenite. Hence it was found impossible, as had been at first intended, to reproduce the figures directly from an electrotype taken from the iron. The figures are cubical rather than octahedral in arrangement and more closely approach the Jewellite group of Meunier, particularly the Dickson County iron; in form the entire arrangement resembles the Schwetzite Werchne-Udinsk Siberia group, but the figures are about one-third their diameter. It also resembles somewhat the Trenton, Wisconsin iron, but still differs from all of these. Troilite is present in nodules 5 to 10$^{mm}$ in diameter and also filling the irregular fissures some 50$^{mm}$ long and 1 to 3$^{mm}$ wide. The figures, shown on Plate V, are an exact reproduction natural size by the admirable Kurtz process.

## Art. XLII.—*Combinations of Silver Chloride with other Metallic Chlorides;* by M. Carey Lea.

In a series of papers lately published, I have expressed the view that the principal and characteristic product of the action of light on the silver haloids is a combination of the haloid with a small proportion of its own subsalt. Such was the result of my analyses, and the opinion was supported by the tendency which the silver haloids were found to have to unite with foreign matters, such as many dyes and other organic compounds, showing the existence in these silver haloids of a singular disposition to form compounds outside the laws of atomic proportion.

This opinion finds additional support from another argument and a more nearly parallel case, for it appears that silver chloride (and doubtless the other silver haloids) can unite with small quantities of certain other metallic chlorides. That an actual combination, though one quite outside of atomic proportion, takes place, is proved by two facts: first, that the chloride with which the silver haloid unites, though soluble in water, is not removable by water; again, that the properties of the haloid are markedly changed.

This combination with another metallic chloride furnishes a much nearer parallel case to the photosalts than does the combination with a dye. For if silver chloride is found to be capable of taking up a small quantity of ferric or other chloride, and of retaining it so firmly that it cannot be removed by washing, and only with some difficulty by HCl, we are thereby justified in admitting that the silver haloid may easily form a stable combination with a small proportion of its own subsalt.

In all these compounds the tendency seems always to the combination of a large proportion of the silver haloid with a small one of the other substance, whether the latter is a dye, another chloride, or a silver subsalt—all show the same disposition, so that I am justified in saying that my view of the nature of the photosalt is supported by the existence of many analogous bodies.

These compounds of silver chloride and other metallic chlorides form when the silver haloid is in presence of their solutions at the moment of its precipitation.

*AgCl with $Fe_2Cl_6$.*—When to dilute HCl is added, first, ferric chloride, then solution of silver nitrate, the silver chloride thrown down is not white but buff-colored. The ferric chloride which has united with the silver chloride cannot be removed by washing. Agitating with HCl dissolves out part, but not all. It is very interesting that this small quantity of iron pro-

foundly affects the sensitiveness of the silver salt to light. To make an accurate comparison, two solutions of silver chloride were precipitated, the one from pure HCl, the other from HCl mixed with $Fe_2Cl_3$; both were shaken up with HCl, so as to remove all the more loosely combined iron salt from the one, and to place the two under exactly corresponding conditions, the presence of the iron salt alone excepted. They were then washed. When both were exposed together to light, the difference was extraordinary. The normal AgCl had passed to a full violet, with an exposure which produced on the other scarcely any visible effect. Even after an exposure to diffuse light of two hours, the difference was still very striking.

*AgCl with CoCl.*—When cobalt chloride is added to HCl, and then solution of silver nitrate, a pinkish precipitate is obtained, whose sensitiveness to light is less than that of normal silver chloride. But the diminution of sensitiveness is far from being so great as in the case of AgCl precipitated in presence of ferric chloride.

*AgCl with other chlorides.*—Both nickel chloride and manganous chloride attach themselves to silver chloride when the latter is precipitated in their presence. Cupric chloride seems to have no such tendency. Gold chloride shows a marked tendency to attach itself to AgCl. When silver nitrate is added to dilute HCl with which a little auric chloride has been mixed, the precipitated AgCl has a reddish shade. Continued washing renders this paler but does not seem to remove it. After ten decantations, each with a hundred volumes of water, the color imparted by the gold is still visible. What influence the auric chloride has on the sensitiveness of the silver salt it is not easy to say, as the gold present is quickly reduced by exposure to light, so that the AgCl, instead of passing to violet and chocolate as in the case of pure AgCl, gradually darkens to a pure black.

The facility with which these compounds are formed explains the necessity in analytical determinations of silver as chloride, for digestion for a considerable time with dilute HCl. Even then it is very doubtful if all the foreign chloride is removed. Ferric chloride is especially adherent. Indeed it has been said that when iron once comes into contact with silver it is next to impossible to get rid of it, and the reason lies in the strong affinity which the two chlorides have for each other. Accordingly much silver nitrate sold as absolutely pure contains iron, evidently carried down with the silver chloride when precipitated in the manufacture.

These reactions of AgCl are interesting in several ways. They support the theory I have proposed, of the photosalts

being compounds of two chlorides of silver not combined in definite proportions, by establishing the existence of other analogous compound chlorides.

Again, the sensitiveness to light of AgCl is so strongly modified by mere traces of ferric chloride, that evidently a quantity of the latter substance, quite too small to visibly affect the color of the AgCl, may materially change its sensitiveness, thus affording an illustration of what takes place in the latent image, where the presence of a quantity of $Ag_2Cl$, too minute to be visible, is sufficient to powerfully influence the substance combined with it.

It also furnishes an explanation for a well-known fact that has hitherto seemed anomalous. It has long been known that a trace of mercuric chloride suffices to greatly diminish the sensitiveness of silver chloride to light. This isolated fact now becomes simply one of a series; AgCl combines with a small proportion of mercuric chloride just as it does with other metallic chlorides, those of the iron triad for example, and does not give it up when washed.

Debray (quoted in Gmelin-Kraut, article Silver), has indeed expressed the opinion that the mercuric chloride can be entirely removed by washing with water. To fix this point I have sought for a convenient means of detecting small quantities of mercuric chloride in presence of AgCl, and have found it in a solution of stannous chloride made strongly acid with HCl. Pure AgCl is not darkened by this reagent, provided that light is carefully excluded, but if mercuric salt is present, a brown or brownish black coloration results. Long washing has with me wholly failed to remove the mercuric salt. I therefore look upon the combination as one of considerable stability.

All these combinations diminish the sensitiveness of AgCl, but this effect is greatly stronger with those chlorides which easily part with one equivalent of chlorine, as we saw in the case of ferric chloride. Mercuric chloride acts in the same energetic way.

It seems indeed that the reduction of sensitiveness in these cases is somewhat out of proportion to the amount of chlorine that could be yielded up by the trace of the foreign chloride which is combined with the AgCl. But this is, perhaps, to be explained by this trace of chlorine holding in check the initial movement toward reduction.

It is worth observing that experiment and observation are constantly tending to enlarge the number of substances with traces of which the silver haloids show themselves capable of uniting, with great modification of their properties as a consequence.

The reduction of sensitiveness that results from the presence of

certain other chlorides, will undoubtedly in the future be of great value in aiding toward a solution of the problem of rendering permanent photographic images in natural colors. Indeed, it was Poitevin, I think, who found that his colored images resisted light better when treated with lead chloride and dextrine. The property was observed, but the nature of the action remained obscure. We now see its explanation in the tendency of the lead salt to check reduction. Zinc chloride I found available like lead chloride, to regenerate white silver chloride by the action of light on colored photochloride, and thus to give aid toward that very difficult requirement in heliochromy, that white light shall express itself by producing white.

Philadelphia, September 24, 1887.

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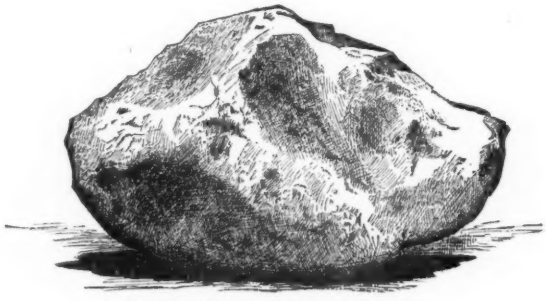
ART. XLIII.—*The Rockwood Meteorite;* by J. EDWARD WHITFIELD.

THE Rockwood meteorite was found about the middle of March, 1887, by Mr. Elihu Humbree on the range of the Crab Orchard Mountains. The field in which it was picked up is now owned by Mr. W. B. Lenoir, and is situated 8½ miles west from Rockwood, Tenn., in Cumberland County. The material for analysis was received from Messrs. Ward and Howell, of Rochester, N. Y., the present owners of the meteorite, to whom we are indebted for the privilege of description.

1.



$\frac{1}{6}$ Natural size. (The main mass.)

There were three pieces found, the smallest measuring $4\times3\times2\frac{1}{2}$ inches and weighing 3 pounds $10\frac{1}{2}$ oz.; the next larger measuring $7\frac{1}{5}\times6\frac{1}{2}\times2\frac{3}{8}$ inches and weighing 5 pounds $13\frac{1}{2}$ oz.; and the largest, an irregular egg-shaped mass a little flattened on one side, measuring $14\frac{3}{4}\times10\times8\frac{1}{2}$ inches, with a weight

of about 85 pounds, and sp. gr. of 4·240. An idea of the appearance of this piece can be had from the foregoing cut, which is from a photograph reduced to $\frac{1}{3}$ natural size.

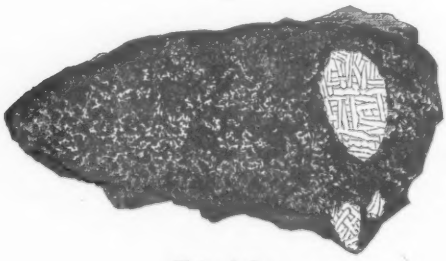
The mass is quite brittle, very hard to saw, but easily broken by hammering. Cut slices show many irregularly shaped stony fragments with some nodules, the largest seen being about $\frac{5}{8} \times \frac{3}{8}$ inches on the surface diameter. In the larger slices the stony part is so broken as to give the polished surface a brecciated appearance. In analysis the metallic portion was freed from the mineral part by crushing to rather fine particles and separating by the aid of a magnet. This was again treated in the same manner, and the resulting metal washed with alcohol and quickly dried; by this method it was found possible to free the metal from all but the merest trace of stony substance.

The metallic portion proved to be an alloy, rich in nickel, as is shown by the following figures:

| | |
|---|---|
| Fe | 87·59 |
| Ni | 12·09 |
| Co | trace |
| Cu | " |
| P | none |
| S | " |
| | 99·68 |

The metallic grains seem to be quite evenly distributed through the mass. In but one instance does a nodule appear to have attained a size larger than that of a pea, and on the section of this nodule we were able to obtain the Widmannstätten figures by etching. Cut No. 2 shows the polished slice containing this nodule, natural size.

2.



Natural size.

The rocky part, after being freed as well as possible from metal, was finally ground and digested with dilute hydrochloric acid, and the resulting soluble and insoluble portions investi-

gated separately, but from the fact of there being a number of minerals mixed together, no satisfactory conclusions could be drawn from the examination. The mass was therefore analyzed as a whole with the following result:

| | | |
|---|---|---|
| $SiO_2$ | 41·92 | |
| $Al_2O_3$ | 9·27 | |
| FeO | 22·94 | |
| CaO | 9·09 | |
| MgO | 8·76 | |
| Fe | 3·75 | |
| Ni | 1·74 | |
| Cl | 0·18 | $=O\cdot32\ FeCl_2$ |
| P | 0·65 | |
| S | 1·58 | |
| | 99·88 | |

By the analysis of the portions soluble and insoluble in dilute acid, it was found that the greater part of the lime and but a trace of the magnesia had gone into solution, proving the absence of olivine, and giving good grounds for the supposition that the rocky portion is mainly a mixture of anorthite and a silicate related to augite, but very rich in iron.

It will be noticed that the ratio between iron and nickel in the metallic portion is greater than that in the rock. This is accounted for by the fact that in the rocky part of the meteorite, the iron, as metal, has been greatly oxidized, as is shown by the large amount of rust covering the specimen, caused no doubt by the chloride of iron present, and is reckoned as FeO, accounting for the large proportion of iron in the supposed augite.

Owing to the bad condition of the fragments subjected to analysis we have no grounds on which to compute the phosphorus and sulphur as schreibersite and troilite, but from the fact of these minerals being among the more common constituents of this class of meteorites, and also that in the main analysis of the rock portion phosphorus and sulphur were found, it is probable that the phosphide and sulphide of iron are two of the minerals present.

One of the polished slices contained a nodule of about $\frac{1}{2}$ inch diameter, which was sacrificed in order that its nature might be determined, and the following figures give the results of analysis. The mineral was finely ground, the metallic portion, if any, separated by aid of the magnet and digested in dilute hydrochloric acid.

The insoluble portion was found to be 94 per cent, the composition of which is

| | |
|---|---|
| $SiO_2$ | 51·85 |
| $Al_2O_3$ | 4·52 |
| FeO | 13·26 |
| CaO | 1·09 |
| MgO | 29·28 |
| | 100·00 |

Giving the ratio of R″O to $SiO_2$ = ·93 : ·86, which corresponds well with the mineral enstatite, although in this case much of magnesia is replaced by iron. The soluble portion consisted of iron with a slight trace of nickel, which tends to show that the nodule contained some metallic particles which it was impossible to extract with the magnet. During the digestion in acid, as no sulphuretted hydrogen could be detected, we infer the non-existence of sulphides in the nodule.

The total mineral was also analyzed with the following results:

| | |
|---|---|
| $SiO_2$ | 49·96 |
| $Al_2O_3$ | 4·75 |
| FeO | 15·97 |
| CoO + NiO | trace |
| CaO | 1·15 |
| MgO | 28·15 |
| | 99·98 |

This meteorite then is a lithosiderite poor in metal, the metallic portion not exceeding 16 per cent of the mass. The stony part is probably anorthite and enstatite.

Chem. Lab. U. S. G. S., Washington, D. C., Aug. 26, 1887.

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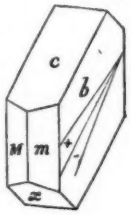
ART. XLIV.—*Triclinic Feldspars with twinning striations on the brachypinacoid;* by S. L. PENFIELD and F. L. SPERRY.

ON looking over the cleavage specimens of plagioclase feldspar in the collection of Professor Geo. J. Brush, especially those which would be classed as albite or oligoclase, we were surprised to find how many of them showed striations due to twinning on $i\text{-}\breve{1}$ (010), in addition to the ordinary striations on the basal plane. These striations on the brachypinacoid have not been very prominently noted in text-books on mineralogy, and we have thought that it would be of interest to study them in connection with the chemical analyses of the feldspars. We are largely indebted to Professor G. vom Rath for our knowledge of the twinning striations on $i\text{-}\breve{1}$ of the plagioclase feldspars. He showed * that they resulted from twinning accord-

* Jahrb. f. Min., 1878, 689.

ing to the so-called pericline law, that is the twinning plane is a plane at right angles to the macro-axis, $\bar{b}$. The two individuals in twin position are not united by the basal plane, when they would not quite match along the composition face, but by a plane deviating a little from the base, passing through the $\bar{b}$ axis, and so inclined that the four plane angles which its intersection makes with the prisms *M* and *m* and pinacoid *b* are all equal, this is the so-called rhombic section (*der rhombische Schnitt* of vom Rath). Owing to the variation in the axial angles of the triclinic feldspars, especially the angle between the $\breve{a}$ and $\bar{b}$ axes, which in albite = 87° 51½′, in anorthite 91° 12′, the direction of the rhombic section changes very greatly. This will be better understood from the accompanying figure and the following table copied from Tschermak.* If the direction above the line, parallel to the edge $c : b$, be called positive + and below negative −, the direction of the rhombic section in the different feldspars in the albite-anorthite series should be about as follows:




| | | | % $Na_2O$ | % CaO |
|---|---|---|---|---|
| Albite $Na_2Al_2Si_6O_{16}$ ..... | Ab, | +22 | 11·8 | 0 |
| Oligoclase ..... | $Ab_3An_1$ | +4 | 8·7 | 5·2 |
| Andesine ..... | $Ab_1An_1$, | −2 | 5·7 | 10·4 |
| Labradorite ..... | $Ab_1An_3$, | −9 | 2·8 | 15·3 |
| Anorthite $Ca_2Al_4Si_4O_{16}$.... | An | −18 | ·0 | 20·1 |

If these striations can be found, therefore, on $i\text{-}\breve{i}$, they should give a ready means of determining the position of the feldspar in the albite-anorthite series. The following analyses will serve to show the relation between the direction of the striations and the chemical composition of the feldspars.

*Oligoclase and Albite.*—In Professor Brush's collection, leaving out of consideration the crystallized specimens of albite and pericline, there are cleavage specimens from six different localities which show distinct striations upon $i\text{-}\breve{i}$. There are also a few others in which the striations are not very distinct, in all, nearly one-half of the specimens show these striations. On the basal plane the striæ are usually a little finer than on $i\text{-}\breve{i}$, and a rectangular marking is sometimes seen due to the meeting of the two sets of striations according to the albite and pericline laws. There is also a tendency for the feldspars to separate, or cleave, parallel to the rhombic section and a combination parting of this with the basal cleavage causes the feldspar to break out into wedge-shaped blocks. The following six analyses by Mr. Sperry are arranged according to the

* Lehrbuch der Mineralogie, 1884, 458.

percentage of CaO. All satisfy Tschermak's formula very well as mixtures of $Na_2Al_2Si_6O_{16}$ and $Ca_2Al_4Si_4O_{16}$. In VI there is an unusually large percentage of $K_2O$ due to an admixture of microcline, which could be distinctly seen with the microscope on a section parallel to the basal cleavage. Below the analyses the proportion of anorthite to albite is given, $K_2O$ being left out of the calculation, together with the per cent of anorthite, the direction of the rhombic section and the extinction angle upon *i*-$\bar{i}$ measured with the polarizing microscope.

| | I. | II. | III. | IV. | V. | VI. |
|---|---|---|---|---|---|---|
| | Branchv'le, Conn. | Hitteroe, Norway. | Haddam, Conn. | Miner'l Hill, Delaware Co., Pa. | Danbury, Conn. | Pierrepont, St. Law. Co., N. Y. |
| No. in Brush collection, | *1790* | *1758* | *1757* | *1782* | *1764* | *1791* |
| $SiO_2$ | 66·58 | 66·83 | 66·06 | 66·34 | 65·73 | 63·76 |
| $Al_2O_3$ | 21·26 | 20·88 | 21·57 | 20·72 | 21·32 | 22·67 |
| $Fe_2O_3$ | ·07 | ·25 | ·18 | ---- | ·12 | ·41 |
| CaO | 1·18 | 1·46 | 1·80 | 1·85 | 1·95 | 3·05 |
| $Na_2O$ | 10·26 | 10·36 | 9·57 | 9·44 | 9·66 | 6·89 |
| $K_2O$ | ·76 | ·70 | 1·01 | ·98 | ·95 | 3·60 |
| Ign. | ·16 | ·27 | ---- | ·38 | ·19 | ·40 |
| | 100·27 | 100·75 | 100·19 | 99·71 | 99·92 | 100·78 |
| Specific gravity | 2·610 | 2·632 | 2·633 | 2·627 | 2·628 | 2·622 |
| Ratio An : Ab | 1 : 16·0 | 1 : 13·0 | 1 : 9·6 | 1 : 9·2 | 1 : 9·0 | 1 : 4·1 |
| Per cent of anorthite, | 5·87 | 7·25 | 8·94 | 9·20 | 9·70 | 15·17 |
| Rhombic section | +12° | 14° | 13° | 12° | 10° | 10° |
| Extinction on *i*-$\bar{i}$ (010), | 15° | 15° | 16° | 12° | 15° | 6° |

All of the above feldspars, with the exception of No. 6, are very similar and could be classified as albites, as they contain more than nine parts of the albite molecule to one of anorthite. Their extinction angle, 12°–16°, is near to that of pure albite +19°. In No. 6 we notice no very perceptible change in the direction of the rhombic section, as we should expect for so large an addition of the anorthite molecule; there is quite a perceptible change, however, in the direction of the extinction angle. Judging from the above, however, it will be safe to predict that where the striations on *i*-$\bar{i}$ make an angle of about +12°, the feldspar will be a mixture of albite with from five to ten per cent of anorthite.

*Feldspars more basic than oligoclase.*—On the material at our disposal we have not been able to find many examples with striations on *i*-$\bar{i}$. One fine specimen, labeled labradorite from Labrador (No. 1732 in Professor Brush's collection), polished on the brachypinacoid to show the beautiful colors so common in that species, shows three cleavage surfaces: two basal cleavages covered with very distinct wide striations and one *i*-$\bar{i}$,

which is not polished, with very distinct striations running practically parallel to the edge between the base and $i\text{-}\breve{\imath}$. Were it not for the play of colors on $i\text{-}\breve{\imath}$, the striated brachy-pinacoid could not be told at a glance from the striated basal plane. How common such specimens are we cannot say; in the student's collection in the Boston Institute of Technology there are several specimens, probably all from one block, of exactly the same character. An analysis of this feldspar by Penfield is given below:

| | | Ratio. | | Albite. | Anorthite. |
|---|---|---|---|---|---|
| $SiO_2$ | 54·75 | ·912 | | ·528 (6) | + ·384 (2) |
| $Al_2O_3$ | 27·76 | ·269 | ·273 | ·088 (1) | + ·185 (0·97) |
| $Fe_2O_3$ | ·69 | ·004 | | | |
| $CaO$ | 10·60 | ·189 | | | ·189 (0·98) |
| $Na_2O$ | 5·13 | ·083 | ·088 | ·088 (1) | |
| $K_2O$ | ·53 | ·005 | | | |
| Ign. | ·56 | | | | |
| | 100·02 | | | | |
| Sp. gr. | 2·684 | | | | |

The ratio of anorthite to albite = 1 : 0·93; per cent of anorthite, 52·45. Rhombic section ± 0, extinction angle on $i\text{-}\breve{\imath}$ = −19°. In this example the rhombic section, being parallel with the base, agrees very closely with the above table from Tschermak, where in andesine with $Ab_1An_1$ the rhombic section has the direction −2° and the extinction angle −16°.

The above analytical results give, therefore, a very satisfactory agreement both as regards the direction of the rhombic section and the extinction angle on $i\text{-}\breve{\imath}$ with the tables given in Tschermak's Mineralogy. One other specimen in Professor Brush's collection (No. 1712), labeled anorthite from Mt. Somma, contains a fractured crystal with striations on $i\text{-}\breve{\imath}$ inclined −13°. Although no material could be obtained for analysis, it is safe to assume that an analysis would show no, or only a very slight, percentage of $Na_2O$.

The variations in the angles of the plagioclase crystals is considerable, and, as vom Rath has shown, they affect the direction of the rhombic section very perceptibly; however, the change in position of the rhombic section from +22° to −18 is so great that a careful consideration of the direction of the striations will enable one to decide within very narrow limits what position any plagioclase will hold in the albite-anorthite series.

In closing, we wish to express our thanks to Professor Geo. J. Brush for his liberality in allowing us to use the material from his collection for carrying out this investigation.

Mineralogical Laboratory, Sheffield Scientific School, June, 1887.

# SCIENTIFIC INTELLIGENCE.

## I. Chemistry and Physics.

1. *On the Production of Ozone from pure Oxygen.*—Having had occasion to prepare oxygen gas of a high degree of purity and to transfer it to experimental apparatus of various kinds without contamination, Shenstone and Cundall have taken the opportunity to study the conditions of the preparation of ozone from pure oxygen under the influence of the silent electric discharge. For the production and storage of the oxygen, the authors contrived a special form of apparatus made entirely of glass, the various parts of which are united by fusion. It consists essentially of a flask for generating the oxygen, containing a previously fused mixture of potassium and sodium chlorates in molecular proportions, and a cylinder of about a liter capacity, for storing it. To the right of this reservoir and to the left of the flask, connections are made with Sprengel pumps, glass taps of special construction being placed between. A third tap closes the tube between the flask and reservoir. At its lower end the storage cylinder is connected with a mercury reservoir, and sampling tubes are provided by which specimens of the gas may be obtained for examination. The precautions required in filling the reservoir are detailed in the paper. It was found that the most satisfactory reagent for determining the purity of the oxygen was phosphorus, and it was found possible by means of a special pipette, to avoid the introduction of any inpurity. So that after the absorption, not more than 1/5000 of residual gas remained. The authors believe however, that the purity of the oxygen actually exceeds this value. For the ozone experiments, the oxygen was collected in a glass cylinder, into the top of which the neck of a cylindrical bulb was fastened, the bulb projecting into the cylinder, leaving an annular space between the walls of the two. At its lower end the cylinder terminated in a smaller S-shaped tube upon which was a globe containing phosphoric oxide. Nine months after filling the apparatus with oxygen, the outer end of the S-shaped tube was broken off under sulphuric acid, the level of the liquid noted, and the enclosed gas electrified by connecting sulphuric acid placed in the cylindrical bulb, and a strip of tin foil opposite it on the outside of the glass cylinder, with the terminals of an induction coil capable of giving a four or five inch spark. A steady diminution in the volume of the gas set in, indicated by the rise of the acid in the S-shaped tube, until in the first experiment lasting 24 hours the contraction indicated that a conversion into ozone had taken place, of about 7·5 per cent of the oxygen employed. In a second experiment the gas was electrified at intervals for three days and the contraction indicated a conversion of 15 per cent of the oxygen into ozone. Doubting the accuracy of estimating the

amount of ozone formed from the contraction observed, the authors introduced some turpentine into the apparatus and noted the absorption. It amounted to about 11·7 per cent of the original volume of the oxygen. Another cylindrical tube provided as above with the cylindrical bulb and lateral reservoir containing phosphoric oxide, but also containing a small bulb of pure mercury, was filled with pure oxygen and electrified, and the bulb broken. The surface of the mercury lost its convexity and the mercury adhered strongly to the glass. In 24 hours, however, no signs of oxidation appeared on the mercury and after a few days it returned to its original condition, no trace of ozone being detectible within the apparatus. Hence the authors conclude that perfectly dry ozone is completely decomposed by mercury without oxidation of the metal. In order to study the character of the silent discharge, two strips of tin-foil were placed on the remote sides of sheets of patent plate glass, and these were mounted on the jaws of a small parallel vise, so that they could be moved to or from each other. At one centimeter distance, the discharge consists of a few noisy sparks. As they are approached the sparks diminish and the glow discharge increases, till at a millimeter, the glow greatly predominates. If now a little warm moist air be blown between the plates the glow vanishes, the discharge again consisting of a few large sparks. Hence it would appear that the high yield of ozone in dry oxygen is due to the fact that the condition of the interior surfaces of the apparatus are exceedingly favorable to the occurrence of the most efficient form of electric discharge.

In a subsequent paper, SHENSTONE and CUNDALL described a simple form of apparatus for showing as a lecture experiment, Loret's proof of the composition of ozone, which consists in submitting a fixed quantity of oxygen to the action of the electric discharge and of turpentine in succession and of observing the changes of volume which occur. A somewhat wide tube has the neck of a cylindrical bulb sealed into its upper end while its lower has two lateral openings, one of considerable size closed by a cork, the other connected to a tube passing vertically upward parallel to the large tube and closed with a tap. Near the top of the wide tube and on the opposite side is a re-curved tube filled with sulphuric acid colored by indigo, serving as a manometer. A bulb containing turpentine is introduced into the tube through the lateral tubulure, the apparatus is filled with oxygen, immersed in cold water, and the electric discharge passed between sulphuric acid contained in the cylindrical bulb and a strip of tin-foil on the outside of the main tube. The change of level in the liquid in the manometer shows the contraction. By shaking the apparatus the turpentine bulb is broken and the absorption of the ozone is effected.—*J. Chem. Soc.*, li, 610, 625, July, 1887. G. F. B.

2. *On the Density of Nitrogen dioxide and of Nitrogen tetroxide at* −100°.—In the hope that at very low temperatures, the unsaturated molecules NO and $NO_2$ dissociated at ordinary tempera-

tures would combine to form saturated molecules $N_2O_2$ and $N_2O_4$, DACCOMO and VICTOR MEYER have submitted these gases to a temperature of −100°. By means of a simple apparatus, nitrogen tetroxide was exposed to a temperature in two experiments of −96° and −107° and its density was found to be the same as that possessed by it at ordinary temperatures. No evidence either of the existence of $N_2O_2$ at these temperatures was obtained; so that if this compound exists it is completely dissociated below this point. The apparatus used consisted of two exactly similar air thermometer bulbs, filled the one with air the other with nitrogen tetroxide. The liquid employed as a seal was sulphuric acid, the level being made exactly the same in both tubes. The bulbs were placed close together and covered with a mixture of solid carbon dioxide and ether. The contraction was exactly the same in both tubes, showing that the tetroxide had not changed its density.—*Ber. Berl. Chem. Ges.*, xx, 1832, June, 1887. G. F. B.

3. *On the Behavior of Phosphorus, Arsenic and Antimony at a white heat.*—MENSCHING and VICTOR MEYER have obtained evidence that phosphorus and arsenic suffer a marked loss of vapor density at a red heat and that at a white heat they approximate the values $P_2$ and $As_2$, although the densities corresponding to these molecules have not yet been observed. With regard to antimony, the authors have succeeded in determining its hitherto unknown vapor density, using a porcelain vessel. This element behaves in an entirely different way from phosphorus and arsenic, no molecular weight corresponding to the formula $Sb_4$ existing. On passing into the state of vapor, which it does with difficulty, it assumes at once a molecular condition represented by a formula smaller than $Sb_4$ and also than $Sb_2$. So that its actual molecular size is either $Sb_2$ or $Sb_1$, but which of these has not yet been determined owing to the difficulties of obtaining a normal antimony vapor having an invariable expansion-coefficient at this high temperature.—*Ber. Berl. Chem. Ges.*, xx, 1833, June, 1887.

G. F. B.

4. *On a Portable Apparatus for the rapid estimation of Carbon dioxide in air.*—On account of the importance for hygienic purposes, of rapid and accurate determinations of carbon dioxide in samples of air, PETTERSEN and PALMQUIST have devised a portable apparatus for this purpose with which in a few minutes the amount of $CO_2$ in a specimen of air can be determined to within 0·01 per cent. Referring to the original paper for an illustration and description of the apparatus, it may here be stated that each experiment consists of three distinct stages of operation. In the first the air to be examined is drawn into the apparatus, and measured. The cylindrical vessel in which it is contained has a capacity of 18$^{cc}$. It terminates below in a graduated scale tube, the lower part of which has a larger diameter than the upper, a mercury reservoir being connected to the lower end by a rubber tube. Above the measuring vessel is connected to a delicate

horizontal manometer. Each division of the upper portion of the scale tube corresponds to 1/10000 of the volume of this measuring pipette, each division of the lower portion to 1/1000 of this volume. The measurement is effected by adjusting the level of the mercury till the manometer index stands at zero and then reading off the volume on the scale. The second operation consists in transferring the air thus measured to an Orsat tube containing potassium hydrate and allowing it to remain one or two minutes to effect the absorption of the carbon dioxide. The third operation consists in returning it to the measuring pipette, adjusting the mercury to the manometric zero, and reading off the diminution of volume on the scale tube. For air containing up to 0·4 per cent of $CO_2$ the finer tube is employed; but for air more impure than this, the lower and larger scale tube is used. The results of measurements made with this apparatus compared with those given by Sondén's larger apparatus and by Pettenkofer's method are entirely satisfactory.—*Ber. Berl. Chem. Ges.*, xx, 2129, July, 1887. G. F. B.

5. *On the Atomic Weight of Silicon.*—The atomic weight of silicon which is usually employed rests upon two not very accordant determinations of the ratio of silicon tetrachloride to silver made by Dumas. THORPE and YOUNG have undertaken a new determination of this important constant, based on an estimation of the ratio of silicon tetrabromide to the silicon dioxide formed on treating the tetrabromide with water. The tetrabromide was prepared by passing bromine vapor over a strongly heated mixture of pure silica and finely ground willow charcoal such as is used in the manufacture of gunpowder. The rectified product was shaken with mercury, decanted, placed in contact with copper for some weeks and distilled in a current of dry nitrogen. It was absolutely clear and colorless and boiled constantly at 153°. Bulbs were filled with the tetrabromide without exposure to air, by the same method which was used by Thorpe for titanium. A bulb, containing a weighed quantity of the bromide, was placed in a well stoppered bottle with 10 times its weight of water, and broken by shaking. The turbid liquid was decanted into a tared crucible and evaporated over a water bath, an equal volume of water being evaporated under the same conditions in the tare. The two crucibles were dried in an air bath at 160°, then ignited in a muffle, allowed to cool and weighed by the method of vibration, employing all the necessary precautions. Nine separate determinations were made, giving values ranging from 28·243 to 28·429 as the atomic weight desired. The mean value obtained was 28·332, which the author adopts as the most probable value for the atomic weight of silicon.—*J. Chem. Soc.*, li, 576, June, 1887. G. F. B.

6. *On the Atomic Weight of Gold.*—THORPE and LAURIE have made a very careful re-determination of the atomic weight of gold, using for this purpose potassium brom-aurate, prepared by the action of pure bromine in excess upon pure gold

(999·88 fine by mint assay) in presence of an equivalent quantity of pure potassium bromide, and water. After three recrystallizations the salt was considered pure. An unweighed quantity, from 12 to 15 grams, was placed in a large porcelain crucible, previously weighed against a precisely similar crucible, and then heated for some hours at a temperature gradually increasing to about 160° after which it was still more strongly heated over a small Bunsen flame. The auric bromide is readily decomposed and the mixture of gold and potassium bromide is then weighed against the crucible used as a tare. Three ratios were made use of for fixing the atomic weight. The first was that of the gold to the potassium bromide, obtained by dissolving out the latter from the above mixture and weighing the remaining gold. The second ratio was that of the residual gold to the silver required to precipitate the bromine in the whole of the potassium bromide. And the third ratio was that of the residual gold to the silver bromide itself thus produced. All possible precautions were taken to secure accurate results. Eight determinations were made by the first method, the atomic weight varying between 196·85 and 196·90. Nine determinations by the second method gave values varying from 196·78 to 196·90. Eight estimations by the third method gave 196·77 as a minimum and 196·91 as a maximum value. But it is better to deduce the final results from the aggregate weights of the gold, potassium bromide, silver and silver bromide. The mean of the first series thus calculated is 196·876; of the second 196·837; and of the third 196·842. The mean of these values is 196·852, with a probable error of ±0·0082. This the authors consider to be the atomic weight of gold.—*J. Chem. Soc.*, li, 565, June, 1887. G. F. B.

7. *On the Occurrence of Alkaloid-like Bases in Paraffin Oil.*—WELLER has called attention to the occurrence of basic bodies resembling the alkaloids in a yellow paraffin oil of sp. gr. 0·850 to 0·860, obtained as a bye-product in the Saxony paraffin works. To obtain these bases 500 kilograms of this paraffin oil were agitated with dilute sulphuric acid, the acid decanted, mixed with soda solution and agitated with ether; the operation being several times repeated. A dark brown oily residue was left after distilling off the ether which gave on distillation in a current of steam a colorless oil of 0·98 to 0·99 specific gravity and having an intense disagreeable odor, mouldy when cold and recalling pyridine when heated. This oil contained nitrogen but neither sulphur nor oxygen, and distilled unchanged between 220° and 260°. Ammonium oxalate precipitates its solution in hydrogen chloride, the precipitate being white and crystalline. By saturating an alcoholic solution of the bases with oxalic acid, the oxalate is obtained first in fine needles which rapidly increase to large plates, extending through the solution. After recrystallization, the crystals are pearly in luster and have a fatty feel, and are soluble in hot water.—*Ber. Berl. Chem. Ges.*, xx, 2097, July, 1887.

G. F. B.

8. *Photography applied to the flight of birds.*—M. MAREY continues his researches upon this subject and shows that his method of taking photographs of the flight of a bird on a horizontal and also on a vertical plane enables one to reproduce the phenomenon of flight in a zoetrope, and also to study the mechanism of flight. He shows that previous observers have greatly exaggerated the rise and fall of a bird's body during flight.—*Comptes Rendus*, Sept. 5, 1887, p. 422. J. T.

9. *Spectra of Hydrogen, Oxygen and Water Vapor.*—Professor GRÜNWALD of Prague enunciates the following theory of the relationship of the spectra of gases and their compounds. Let $[a]$ be the volume occupied by a primary chemical element, $a$ in the unit of volume of a gaseous substance, A. Let A be chemically combined with a second gaseous body, B, to form a third, C. The element $a$ now takes the form $a'$ and the volume $[a']$. Then the wave lengths, $\lambda$, of the lines in the spectrum of A, which belong to $a$, are to the wave lengths, $\lambda'$, of the lines in the spectrum of C, which belong to $a'$, as $[a]$ is to $[a']$. The wave lengths of the elementary spectrum of hydrogen can be arranged into two groups, $a$ and $b$, which give the lines of the water vapor spectrum when they are respectively multiplied by $\frac{19}{30}$ and $\frac{4}{5}$. The author concludes that hydrogen is composed of the combination of four volumes of the element $a$ with one of the element $b$. The first element, $a$, should be the lightest of gases and lighter than hydrogen. Since it must therefore enter into the constitution of the corona, Professor Grünwald calls it coronium. The $D_3$ or helium line is found in the spectrum of the element $b$, and the author therefore calls $b$ the helium line. The correspondence between the wave lengths calculated by this theory and those actually observed is striking.—*Phil. Mag.*, Oct., 1887, p. 354. J. T.

10. *Earth currents.*—M. LANDERER gives, as the result of his observations during the past nine years, that, on the special line employed by him, the general direction of currents is from south to north. If the frequency of the currents from northeast to southeast be denoted by 1, that of currents in the opposite direction will be 6·7. The maximum intensity occurred about 10 A. M.—*Comptes Rendus*, Sept. 12, 1887, p. 463. J. T.

11. *Electrical standards.*—A committee of the British Association upon this subject submitted, at the late meeting at Manchester, the following resolutions: "1. To adopt for a term of ten years the legal ohm of the Paris Congress as a legalized standard sufficiently near to the absolute ohm for commercial purposes. 2. That at the end of the ten years period the legal ohm should be defined to a closer approximation to the absolute ohm. 3. That the resolutions of the Paris Congress with respect to the Ampère, the Volt, the Coulomb, and the Farad be adopted. 4. That the resistance standards belonging to the committee of the British Association or electrical standard now deposited at the Cavendish Laboratory at Cambridge be accepted as the English legal standards, conformable to the adopted definition of the

Paris Congress." The committee also recommend the adoption of the Watt as the unit of power. "The Watt is defined as the work done per second by the Ampère passing between two points between which the difference of electric potential is one Volt."—*Nature*, Sept. 22, 1887, p. 498. J. T.

12. *Absolute wave lengths.*—From a careful comparison of the observations of Pierre, of Kurlbaum and his own, Mr. L. BELL concludes that the wave length of D is very near to 5896, and consequently all wave lengths based upon Ångström's value are incorrect by at least one part in 8000. Ångström's relative wave lengths are also inexact.—*Nature*, Sept. 29, 1887, p. 524. J. T.

13. *Annalen der Physik und Chemie*, No. 9, for 1887, contains the following articles:

*An investigation on a jet of steam*, by R. v. HELMHOLTZ. The author shows the influence of certain substances in forming clouds of vapor by means of the steam. He also discusses the behavior of the jet under electrical influences. The action of finely divided particles in forming clouds is commented upon.

*On electrical residual charges and induction in dialectrics*, by A. WÜLLNER.

*The Contact Theory*, by FRANZ EXNER. The author tries an experiment to disprove the theory.

*Upon the theory of an experiment by F. Exner on the Contact Theory*, by WILHELM HALLWACHS. The author exposes an error made by F. EXNER.

*On the development of Electricity by the friction of drops of liquid*, by JULIUS ELSTER and HANS GEITEL. This is a careful repetition of Faraday's experiment, with certain amplifications.

*Electrical polarity of Rock crystal*, by W. HANKEL.

*Resistance of Selenium when exposed to light*, by S. KALISCHER. This paper contains various measurements of specimens of selenium.

*Electrolytic separation of metals at the free surface of a solution of a salt*, by Dr. J. GUBKIN.

*Galvanic Polarization*, by FRANZ STREINTZ. This is a careful study of the relation of the oxygen and hydrogen polarization to the polarizing current.

*Electrical conveyance of heat*, by H. HAGA. This is an answer to objections raised by Budde against the author's work.

*Magnetization formula*, by A. VON WALTENHOFEN.

*Electromagnetic rotation phenomena in fluid conductors*, by F. SCHUMANN.

*Separation of white light into complementary colors*, by W. VON BEZOLD. This is a lecture-room experiment, the main feature of which is the employment of a prism and a cylindrical lens.

*Optical peculiarities of certain chemical compounds.* This is a study of the absorption spectra of certain organic compounds, with reference to the constitution of the compounds.

*Experimental investigation upon rotating fluids*, by W. VON BEZOLD. This investigation bears upon the theory of cyclones and tornadoes.

*Designation of the mass system*, by L. PFAUNDLER.

*On a new form of galvanic battery*, by F. FRIEDRICHS. By an attachment similar to the mercury vessel employed in the Toepler air pump, the author regulates the height of liquid in a series of galvanic cells. J. T.

14. *On Pritchard's Wedge Photometer.**—The photometer devised by Professor Pritchard, consists of a wedge of neutral glass which is inserted between the observer's eye and the eye piece of the telescope and moved along until the thickness is sufficient to render a given star invisible. An instrument of this kind has been successfully used in obtaining the measures of the light of the stars given in the Uranometria Oxoniensis. In order to test its value and accuracy some observations have been recently made by Professors Young, Langley and Pickering. The former makes some practical remarks in regard to the ease and convenience of its use based upon the results obtained upon six stars in the neighborhood of $\gamma$ Pegasi and gives estimates of the probable error in the determination of magnitude. He states that the method is much more wearisome to the eye than those involving the equalization of the light as in the double image photometers.

Professor Langley investigated the wedge by means of the bolometer and found that there was a distinct selective absorption throughout the wedge, even in the visible rays; this was feeble in the more luminous part of the spectrum but such that the transmissibility increased from the violet toward the red, and still more beyond the red. In order to decide the question as to the influence of this selective absorption upon the value of the instrument for photometric work, Professor Pickering made a series of measurements with it at the Harvard Observatory and added to these some photographs of the solar spectrum through it. The photometric measures failed to show the gradual diminution in the coefficient of absorption as the thickness increased. The photographs, however, showed that the intensity of the spectrum transmitted fell off rapidly, beyond $\lambda=0{\cdot}41$ becoming entirely invisible at $\lambda=0{\cdot}40$. The opacity of the wedge increased rapidly as the wave-length diminishes, as the bolometer showed. The conclusion is reached that, though valuable results may be obtained by the wedge photometer when skillfully used, the observations show sources of error needing careful study before it can safely be applied to stars of different colors, or to detecting small systematic errors in the star catalogues.

15. *On the Beneficial Effects of Light;* by G. G. STOKES. 100 pp. 12mo. London and New York, 1887. (Macmillan & Co.).—This volume contains four lectures delivered as the third course of Burnett lectures at Aberdeen in November, 1885. They deal with topics which are readily understood and are presented in a simple and agreeable style. They will be enjoyed now in permanent form by a larger audience than that before which they were presented.

* Investigations on Light and Heat, published with appropriation from the Rumford Fund.

## II. Geology and Mineralogy.

1. *The Terminal Moraines of the Great Glaciers of England;* by Professor H. Carvill Lewis.—The investigation here recorded is based upon the important principle that *every glacier at the time of its greatest extension is bounded and limited by a terminal moraine.* Supposed exceptions to this law in Switzerland and elsewhere had been studied by the author and found to be contrary to observed facts. Thus the ancient Rhone glacier, stated by Swiss geologists to be without a limiting moraine at the time of its greatest extension, was found to have one as distinct as those of the Aar glacier, the Reuss glacier, or the Rhine glacier; and the prevalent idea of a "first glacial epoch" in which the glaciers had no terminal moraines was also unsupported by the author's observations.

The great ice-sheet which once covered northern England was found to be composed of a number of glaciers, each of which was bounded by its own lateral and terminal moraines. These glaciers were studied in detail, beginning with the east of England; and the North Sea glacier, the Wensleydale glacier, the Stainmoor glacier, the Aire glacier, the Irish Sea glacier, and the separate Welsh glaciers were each found to be distinguished by characteristic bowlders and to be defined by well-marked moraines. The terminal moraine of the North Sea glacier, filled with Norwegian bowlders, may be seen in Holderness extending from the mouth of the Humber to Flamborough Head, and consists of a series of conical hills enclosing meres. The moraine of the Stainmoor glacier, characterized by blocks of Shap granite, may be followed northward along the coast past Scarborough and Whitby; then west along the Cleveland Hills; then south again through Oulston to the city of York; then west to near Allerton, where the Stainmoor glacier is joined by the Wensleydale glacier—a fine medial moraine marking the line of junction. The Wensleydale glacier is characterized by bowlders of Carboniferous limestone and sandstone, and its lateral moraine is followed northward through Wornald Green, Markington, Fountains Abbey, and along the Permian outcrop to Masham, where it turns west to Wensleydale, passing Jervaulx Abbey, and running up the valley. North of Wensleydale the moraine of the Stainmoor glacier is followed through Richmond to Kirkby Ravensworth and westward to the mountains, where the glacier attained an elevation of 2,000 feet. Thus the Stainmoor glacier, a tongue of the great Irish Sea glacier, had been divided into two branches by the Cleveland Hills, one branch going south to the city of York, which is built on its terminal moraine, the other branch flowing out of the Tees and being deflected southward along the coast by the North Sea glacier, with which it became confluent.

The Irish Sea glacier, the most important glacier of England, came down from Scotland, and, being reinforced by local ice-

streams, and flowing southward until it abutted against the mountains of Wales, was divided into two tongues, one of which flowed to Wellington and Shrewsbury, while the other went southwest across Anglesey into the Irish Sea. This great glacier and its branches are all outlined by terminal moraines, described in detail. A small tongue from it, the Aire glacier, was forced eastward at Skipton and has its own distinctive moraine. In the neighborhood of Manchester the great moraine of this Irish Sea glacier may be followed through Bacup, Hey, Staley Bridge, Stockport and Macclesfield, being as finely developed as the moraines of Switzerland and America. South of Manchester, it contains flints and shell-fragments, brought by the glacier from the sea-bottom over which it passed. At Manchester the ice was at least 1,400 feet thick, being as thick as the Rhone glacier.

The great terminal moraine now described of the united glaciers of England is a very sinuous line, 550 miles in length, extending from the mouth of the Humber to the farthest extremity of Carnarvonshire, and, except where it separates the Welsh glaciers from the North Sea glacier, everywhere marks the extreme limit of glaciation in England and is an important feature which might well hereafter be marked on the geological map of England.

2. *Les Eaux Souterraines a l' époque actuelle;* Leur régime, leur température, leur composition au point de vue du rôle qui leur revient dans l' économie de l' écorce terrestre; par A. Daubrée. Membre de l' Institut. 2 vols. of 456 and 302 pages, 8vo. Paris, 1887. (Vve. Ch. Dunod.)

*Les Eaux Souterraines aux époques Anciennes;* Rôle qui leur revient dans l'origine et les modifications de la substance de l'écorce terrestre; par A. Daubrée. 483 pp. 8vo, Paris, 1887. (Vve. Ch. Dunod.)

These new works, by the eminent physical geologist of France, M. Daubrée, bear on some of the most interesting of geological questions, and at the same time treat of subjects of wide economical importance. In the first of the two, the existing subterranean waters considered by the author are those of wells, river sources, caverns, artesian wells, saline waters, and mineral springs of various kinds. The relations of wells and water sources to permeable and impermeable strata are illustrated from special facts with regard to superficial deposits, taken in part from the suburbs of various cities, especially those of Europe and Great Britain; and also with a similarly wide range of facts, the author treats of their dependence on the systems of fissures in rocks; on the junction planes of different rocks; their relations to rocks of different kinds, and of different geological periods; their connection with the making of caverns; their emergence as full-made rivers from caverns; their ejection from borings by different gases. The discussion of these various subjects occupy the first volume of 456 pages. The second treats in a general way, without an array of chemical analyses, of the substances held in solution by waters;

their action in the production and alterations of minerals; the relation of subterranean waters to the constitution of the soil, and to temperature; and on geysers and their relations to volcanoes and earthquakes. The work is rich in facts, and contains among its many illustrations very fine copies of photographs, as the "Cascade del Marmore" above Terni; the "Cascades and Cascatelles" of Tivoli, near Rome over travertine deposits; the Beehive Geyser, from one of the photographs of Hayden's expedition; the source of the Fontaine de Vaucluse, in Southern France; a landscape with calcareous incrustations at the source of the Clouange in German Lorraine, etc.; also numerous wood cuts.

The second of the two works has for its subject, as stated on the title page, the part which the older waters have performed in the origin and modification of the rock-material of the earth's surface. The results of the author's investigations with regard to the origin of minerals from subterranean waters and by means of laboratory experiments, described at length in his former invaluable work on Experimental Geology, are here brought forward, along with others, in a general review of the agency of subterranean waters in mineral-making and rock-alteration; the special subjects being the agency of waters in connection with the origin of the minerals of amygdules; of metalliferous deposits and veins; of concretions; of pseudomorphic and metamorphic changes, both as regards composition and structure (the latter including schistosity); and of some of the deposits making the stratified rocks of the globe, questioning whether all the salt deposits of the rocks are of marine origin, and all the limestone and dolomite of organic derivation. The view is sustained and demonstrated that water has been concerned in nearly all the vein-making, and the alterations that have gone forward, and is, therefore, the "mineralisateur par excellence" of geological time. The volume is handsomely illustrated, and contains many figures from the author's former work.

3. *The Connecticut Lake of the Champlain period, north of Holyoke.*—Prof. B. K. Emerson thus describes the lake in the Connecticut valley, made from the melting glacier in the vicinity of Amherst, in a paper on Hampshire County, Mass.:

"Upon the disappearance of the ice from this section of the valley, the great volume of the waters of its melting sustained a lake, which stretched in width to the full limits of the valley, as we have give them, in length from Mt. Toby to the foot of Holyoke, and sent a broad lobe out around Mt. Tom, across Easthampton and Southampton, and on south. Its height was 300 feet above the sea and 200 above low water of the present Connecticut.

The Long Plain in Leverett, North Amherst station, the Bay road, the south spur of Mount Warner, the Florence plain, and West Farms, are level portions of its shore flats. The first and last two are great deltas sent out into its waters. In all its deeper waters the flat, laminated clays were being deposited, while the sands of the deltas were extending out from the shore.

Each layer of the clay, on an average of two-fifths of an inch thick, represents a year's deposit. The clays are, at the Northampton bridge, above 120 feet thick, and at East Street bridge above fifty feet, which would give numbers for the duration of the lake favoring the idea that the Glacial period was not more than 10,000 years ago, one of the shortest estimates.

In these clays I have found an abundant glacial flora, proving that the lake succeeded immediately to the ice, and I have found indications of several re-advances of the ice ploughing up the sands of the lake."

4. *Geological work of Marmots.*—Professor MUSHKETOFF'S account of his explorations in the Caspian steppes contains some interesting remarks on the work done by marmots (*Spermophylus Eversmanii*) in the modification of the surface of the steppe. They made their appearance in the region only a few years ago, but their heaps of earth already cover hundreds of square miles. Like earthworms, they must therefore be regarded as a factor of some importance in modifying the surface of the soil. Their heaps of earth have an average length of 3½ meters, and a width of 2½ meters, with an average height of from 30 to 50 centimeters, and it was found that on each 2 square meters there were no less than five, seven or even eight heaps, each of which represented at least 2 cubic meters of earth removed. It may be safely asserted that on each square kilometer of surface no less than 30,000 cubic meters of earth have been brought to the surface owing to their activity. Their influence on vegetation is also well worthy of notice.—*Nature*, Oct. 6, p. 541.

5. *Slide at Lake Zug of July*, 1887.—On July 5, 1887, at the town of Zug, in Switzerland, a portion of the shore gave way and sank into the lake. About three hours later another much larger adjacent area also suddenly subsided, so that in all an area considerably over two acres, with half of one of the principal streets, was submerged to a depth of about 20 feet. It can be seen that the subsoil consists of coarse gravel and sand, followed after a few feet by soft wet sand and fine mud. According to Professor Heim, this fine mud or sludge reaches to a depth of nearly 200 feet, and the disaster is shown to be due to a flowing out into the lake of this mobile sludge from under the superincumbent weight of buildings and firmer ground. The buildings collapsed as they sank. The catastrophe must have been long impending; the exact cause which precipitated it is undetermined, but a low level of the lake and tremors from pile-driving for new quays are suggested as contributories.—*Geol. Mag.*, Oct., 1887.

6. *Organic origin of Chert.*—Dr. G. J. HINDE has a paper in the Geological Magazine, for October, showing conclusively that the chert from the Carboniferous limestones of Ireland was all made chiefly from the siliceous spicules of sponges, and that the silica of silicified fossils has the same source.

7. *A sketch of Geological History, being the Natural History of the Earth and of its prehuman inhabitants*; by EDWARD

HULL, F.R.S., Director of the Geological Survey of Ireland. 18 pp., 12mo, with an illustrative diagram. London, 1887 (C. W. Deacon & Co.).—This work is a very brief sketch of geological history, giving the chief facts in small compass, without illustrations.

8. *The so-called Harlem Indicolite;* by R. B. RIGGS. (Communicated.)—Some time since a peculiarly bright blue mineral, found at Harlem, N. Y., was sent to the National Museum by Mr. H. D. M. Fair, of Sing Sing, N. Y., for identification. It occurs in slight columnar crystals, in a quartz-feldspar rock abounding in the more or less disintegrated quartz. Is infusible, but loses color on being ignited. It is of rare occurrence and material sufficient for analysis was not at first to be had. The finding of boric acid, however, leads to the conclusion that the mineral was a rare variety of tourmaline. In studying the tourmaline my attention was called to it, and thinking that a partial analysis, at least, might be desirable, something over a gram of quite pure material was finally obtained. The analysis, as follows, at once revealed relations very different from those existing in tourmaline:

| | $SiO_2$ | $B_2O_3$* | $Al_2O_3$ | MgO | $Na_2O$ | $K_2O$ | lgn. | |
|---|---|---|---|---|---|---|---|---|
| | 34·82 | 4·07 | 55·30 | 0·57 | 1·76 | 1·04 | 2·96, | $Fe_2O_3$, CaO, $Li_2O$ *tr.* = 100·52 |
| Ratio | ·580 | ·058 | ·054 | .... | ·029 | ·011 | ·165 | |

Through the kindness of Mr. G. F. Kunz additional material, sufficient for certain determinations made in duplicate, was obtained. The molecular ratios, deduced from the analysis, are very closely expressed by the formula

$$3(H_2O) . (Na, K)_2O . 10(Al_2O_3) . 10(SiO_2)B_2O_3$$

a new boro-silicate. The question of the purity of material analyzed is ever an important one. From the nature of the case it is probable that we have something new to deal with. Impurities coming from either the associated quartz or feldspar would tend to increase the silica and lower the alumina ratios, and that very materially.

That this blue mineral is not tourmaline was also made evident by the microscopic study very kindly made by Mr. J. S. Diller, who, with but little material at his disposal, was nevertheless able to make the following observations. "It is undoubtedly biaxial with remarkable pleochroism, (*c*) ultra-marine, (*b*) reddish violet, (*a*) colorless. The angle of extinction is very small, the largest observed being 8°. Its structure is sub-fibrous, so as to render somewhat obscure the angle of prismatic cleavage."

That this so-called indicolite is not such is certain, that it is a new boro-silicate is highly probable.

Chem. Lab. U. S. G. S., Washington, Aug. 31, 1887.

9. *Notes on some Mineral localities in Litchfield, Conn.;* by M. R. GAINES.—The following observations on the occurrence of washingtonite "in place" in the town of Litchfield, Conn., were

* Mean of two determinations 3·83, 4·31.

made during the writer's residence there between 1872 and 1879. The crystals of washingtonite found were of the ordinary type, flattened hexagonal prisms, with the alternate angles replaced by rhombohedral planes. A. (1.) On the west side of the Wolcottville road, about two miles northeast of the village of Litchfield, is the "Yale Farm," which extends back to the crest of the ridge running north and south. At some distance down the eastern slope of this ridge, a mass of white quartz rock can be seen standing out conspicuously in the open field. Fine crystals of washingtonite were found in this mass itself as also in the blocks on the slope below that had fallen from it. (2.) On the adjoining farm to the south, owned by a Mr. Smith, near the top of the same ridge, beside a cart path leading up to a small cultivated field, the mica schist crops out in a small grove of hickory trees. Here a number of plates of washingtonite, without well defined angles, were found in the rock, associated with well preserved crystals of staurolite of a dark brown color.

B. Just east of the village of Litchfield below the point where the road to the Naugatuck station crosses the Bantam river, there is a mill dam, the abutment at the western end of which is formed by a ledge of mica schist. Here were found fine crystals of pinite, and in quartz veins a few fine specimens of washingtonite. C. The stage road to the Litchfield station on the Naugatuck railroad, crosses Cedar brook at East Litchfield; from this point looking south a bold rocky peak is visible rising abruptly from a narrow valley on the right bank of the stream, which can be easily reached by the wagon road running south. From a farm house on the road to the southwest of the peak, a path runs to the northeast through the fields and woods on the south side. About a hundred and fifty rods from this house, in the mica schist which is transversed by large veins of quartz, were found several crystals of staurolite of unusual size, and also masses of iron ore that proved to be portions of very large crystals of washingtonite. One or two blasts brought to view one perfect crystal of washingtonite, imbedded in the quartz, that measured nearly seven inches in its longest diameter. It fell to pieces when an attempt was made to extract it but the whole crystal must have weighed about six pounds.

Kyoto, Japan, May 20, 1887.

10. *Analysis of Blue Clay from Farmington, Maine;* by F. C. ROBINSON (communicated).—The following analysis of clay was made in my laboratory by Mr. W. V. Wentworth, and may be of interest for reference, especially as I found but few such analyses recorded when I recently had occasion to look up the subject.

| | |
|---|---|
| $SiO_2$ | 63·69 |
| $Al_2O_3$ | 17·02 |
| FeO and $Fe_2O_3$ (mostly FeO) | 10·18 |
| CaO | ·97 |
| $Na_2O$ | 4·02 |
| $H_2O$ | 4·05 |
| | 99·93 |

An approximate mechanical analysis gave the following results:

| | |
|---|---|
| Coarse sand | 3·73 per cent. |
| Fine sand | 22·97 |
| Fine clay | 69·25 |
| Water | 4·05 |
| | 100·00 |

The sand was mostly feldspar with traces of quartz and mica. The clay is used for brick making.

11. *Magnetite crystals pseudomorph after pyrite;* by G. C. HOFFMANN. (Communicated).—A short time back I had sent me for analysis a sample of iron ore from a deposit which occurs in the vicinity of Kinnear's Mills, township of Leeds, Megantic County, Province of Quebec. It consisted of a very fine crystalline magnetite and hematite (the former preponderating), through which was disseminated a large amount of siliceous gangue. Numerous small patches of limonite occurred, interspersed, through the ore, apparently resulting from the decomposition of the pyrites, and there was also a little unaltered pyrite. My assistant, Mr. E. B. Kensick, has made the following observations in regard to some small crystals imbedded in this ore.

The crystals were in the form of small cubes with faces striated parallel to the edges of the pyritohedron. They were black in color and showed a high metallic luster and brilliant faces. The best crystals had cubic edges measuring $1^{mm}$ or less in length. The crystals were very magnetic, being easily picked up with a magnet. Streak brown. Soluble in aqua regia with very slight residue. Gave off water in closed tube. A crystal weighing ·0083 gram lost on ignition ·0008 gram, or 8·6 per cent of water. This crystal was magnetic after ignition and remained unchanged in appearance. It would appear that the crystals are pseudomorphs after iron pyrites in an intermediate stage between limonite and magnetite.

12. *Anwendung der Linearprojection zum Berechnen der Krystalle von* DR. MARTIN WEBSKY. 377 pp. 8vo, with 11 plates. Berlin, 1887, (E. S. Mittler & Sohn).—A peculiar interest attaches to this work in that it was issued after the death of its gifted author; the final supervision has been given by Dr. C. A. Tenne. It is intended to form the third volume of Rose's *Elemente der Krystallographie*, a fourth volume in which series was projected by the same author and in part completed. It contains an exhaustive treatment of the principles and methods of the system of crystallography founded by Weiss and developed by Rose and Quenstedt. Whether this system is the one which, as most convenient of use, is likely to be generally adopted would seem doubtful. It is, however, a great advantage to the students in this line to have the whole subject presented in a manner which, as regards clearness and completeness, meets every requirement. Numerous examples, worked out in all possible fullness, enable the student to go forward without a teacher's assistance.

## III. Botany and Zoology.

1. *Annals of Botany;* edited by Isaac Bayley Balfour, Sidney Howard Vines, and William Gilson Farlow. Oxford, Clarendon Press, vol. I, no. 1, August, 1887.—The character of this welcome journal will be understood when we say that it is worthy of the press from which it comes. The typography and the illustrations leave nothing to be desired; they place the journal on an equality with *Annales des Sciences Naturelles* (*Botanique*) and Pringsheim's *Jahrbücher.* The letterpress is in some respects superior to that of either of the periodicals mentioned and the plates are in every way as good.

The scope of the Annals is wide enough: "Original papers, adequately illustrated, are to be published from time to time, on subjects pertaining to all branches of botanical science, including Morphology, Histology, Physiology, Palæobotany, Pathology, Geographical Distribution, Economic Botany, and Systematic Botany and Classification."

The first number has a preponderance of histology, the four leading articles being devoted to special studies in minute structure, with incidental reference to physiological points. The articles are substantial contributions to our knowledge of the structures, and are of the kind with which readers of Pringsheim, the French Annales, and of Botanische Zeitung are familiar.

Then follow five minor notes, all of interest and two of them of importance. Here again, histology has rather the lion's share. Next, eight pages are given to a laudatory and yet very discriminating criticism of the English edition of Sachs's Lectures on the Physiology of Plants. The reviewer has succeeded in accomplishing just what Dr. Gray has so often done in the pages of this Journal, namely, has shown each reader whether the book under review is the sort of a book which he needs. If the reviews in future numbers can be as comprehensive without prolixity, and as critical without faultfinding as this review of Sachs's work is, we may say that no English-speaking student of botany can afford to be without the Annals.

Forty pages are given up to an enumeration of the books and pamphlets, and of the periodical literature of the science. Although the *Centralblatt* and some other periodicals place these titles before us with more or less completeness, in no journal of our acquaintance do they appear in so convenient a form. Such lists are always useful, but in this instance are rather disappointing, for besides the title there is no hint of the character or even of the length of the paper. It is a pleasure to note the significant fact that one of the editors is an American. During the last few years there has been considerable increase in interest in this country in many botanical subjects other than those which belong to the determination of Phanerogams. It is fitting that an American representative of this interest should participate in the conduct of the new journal. Moreover, Professor Farlow possesses the critical faculty in a high degree, and will see well to it that con-

tributions from this side of the water are no discredit to a journal which starts out so fairly. G. L. G.

2. *Dermatitis venenata;* by JAMES C. WHITE, M.D., Boston, 1887, 8vo, 216 pp.—Professor White has brought together in this treatise a great amount of interesting information of an important character. Restricting this notice to the botanical portion of the work, we may say that the results here presented are altogether surprising. Everyone knows that we have, for instance in the New England States, a few plants which are either poisonous or merely irritant to the skin, such as the two dreaded species of Rhus, one or two nettles and the like. But we confess to a feeling of insecurity when we are informed that the following plants are justly regarded as poisonous to the human skin: Water-plantain, May-apple, Fleabane, Ox-eye Daisy, Mayweed, Golden-rod, Arbor vitae, House-leek, Sundew, Prince's Pine, Asparagus, Flax, Ladies' Slipper, Blood-root, Garget, Monkshood, Baneberry, Wind-flower, Clematis, Larkspur, Buttercups, Mullein, Moose-wood, and even Balm of Gilead. Concerning these common plants and many others, Professor White has brought a formidable indictment sustained by evidence. The whole work is marked by great patience in collecting and sifting testimony from all quarters, and affords a mass of facts for the use of the biologist, as well as the practitioner of medicines. G. L. G.

3. *Lectures on the Physiology of Plants;* by JULIUS VON SACHS, Translated by H. MARSHALL WARD, M.A., F.L.S. Oxford, at the Clarendon Press, 1887, 8vo, 836 pp.—The German edition of these lectures has been already noticed in this Journal; attention was then called to the wide range of subjects treated, to the interesting manner of stating important points, and to the desirability of having the work soon placed before English readers. The translation before us is exceptionally successful. The ideas have been carried over into the English language and not merely into English words. To accomplish this the translator has taken the course which was followed in the preparation of two French translations of previous works by Sachs; whole sentences have been reconstructed, leaving scarcely a trace of the original phrase but never with any sacrifice of the author's meaning. To those who read this work it must be frankly said, that they are presented with certain physiological questions as Sachs sees them, and frequently without any distinct reference to the fact that many of them have two sides. If this treatise is read in conjunction with Vines's Physiology, the student will be placed in possession of the most trustworthy statements of the principles of vegetable physiology. And every reader will rise from his perusal of the two works with the feeling that the two writers have been discriminating in the selection of material, and that both have kept steadily in mind the accepted aphorism, cited by Sachs in his preface,—"the secret of being tedious lies in trying to say all one knows." These two writers have said just about enough in their treatises, and have completely escaped the charge of being tedious. G. L. G.

4. *Comparative Morphology and Biology of the Fungi, Mycetozoa and Bacteria;* by A. DeBary, Professor in the University of Strassburg, Translated by H. E. F. Garnsey, M.A., Revised by Isaac Bayley Balfour, M.A., M.D., F.R.S., Professor of Botany in the University of Oxford. Oxford, at the Clarendon Press, 1887, 8vo, 525 pp.—This translation affords gratifying proof of the strong hold which questions bearing on the structure and life of plants have lately acquired among English-speaking people. A few years ago, no publishing house would have been willing to hazard a publication like the present; the demand for such a treatise would have been confined to specialists and to a few teachers who probably could have made equally good use of the original. But, now, such a volume meets with a considerable sale, even on this side of the Atlantic.

From the good degree of prominence which the author gives to the phenomena presented by these lowest vegetable organisms, the work is of great interest to everyone who is attracted to the study of physiology, and we may also say to pathology. When it is remembered how important a part the organisms last mentioned in the title play in health and disease, we cannot be too grateful that so sound a treatise has been offered to medical students in so attractive a form. As will be noticed in the title above given, those organisms of uncertain place, termed in most of our recent botanical works, Myxomycetes, are treated under the better name of Mycetozoa.

The translation is good throughout, and the choice of technical English equivalents for German scientific terms has been, for the most part, judicious. The translation of such a work as this must hasten the time when there will be some convention with regard to English terminology applied to the morphology of Cryptogams. Such convention would doubtless have due respect to certain prior claims held by the morphology of phanerogams, and which are nowadays somewhat ignored. It is proper that we should express our feeling of obligation to the English press which has given to our students within a short time five volumes of great excellence. G. L. G.

5. *Journal of Morphology;* edited by C. O. Whitman, with the co-operation of Edward Phelps Allis, Jr., Milwaukee. Vol. I, No. 1, Sept., 1887. 226 pp., 8vo, with several plates. Published by Ginn & Co., Boston, at six dollars a year.—This new journal, devoted principally to embryological, anatomical, and histological subjects, comes into existence with all those high qualities as regards grade of scientific memoirs, beauty, fullness of illustrations, paper, typography, and generous capacity that we usually look for as the characteristics of slowly developed and successful maturity. It shows confidence in the scientific spirit of the country by placing itself at once on a level with the journals of the kind abroad, and well merits the success it looks for. Although its active editors are at Milwaukee in Wisconsin, the contributors to this number are from various parts

of the country: Toronto, Canada, the State University of Indiana, Yale College in Connecticut, Bryn Mawr College in Pennsylvania, besides Milwaukee, showing thus its continental sympathies, purpose and demands. Its papers are as follows: (1) Sphyranura Osleri, a contribution to American Helminthology by R. R. WRIGHT and A. B. MACALLUM, of Toronto; (2) Development of the compound eyes of Crangon, by Dr. J. S. KINGSLEY, of Indiana; (3 and 7) Eyes of Molluscs and Arthropods, and Development of the eyes of Vespa, with observations on the ocelli of some insects, by Dr. WM. PATTEN, of Milwaukee; (4) Phylogenetic arrangement of the Sauropsida, by Dr. G. BAUR, Yale College Mus.; (5) Contribution to the history of the Germ-layers in Clepsine, by C. O. WHITMAN, of Milwaukee; (6) The Germ-bands of Lumbricus, by Prof. E. B. WILSON, of Bryn Mawr, Pa.

The second number will probably be issued in November.

6. *Bibliotheca Zoologica* II: Verzeichniss der Schriften über Zoologie welche in den periodischen Werken enthalten und vom Jahre 1861–1880 selbstandig erschienen sind, etc., bearbeitet von DR. O. TASCHENBERG. Lieferung III, pp. 641–960. Leipzig, 1887 (Wm. Engelmann).—The nature and scope of this great catalogue of zoological works have been explained in this Journal (vol. xxxiii, 245) in connection with a notice of parts 1 and 2 of the first volume. The part now issued concludes volume I, and continues the exhaustive method before noted. It is a work which should be at the hand of every one laboring in the various subjects which it embraces.

## IV. MISCELLANEOUS SCIENTIFIC INTELLIGENCE.

1. *Nystrom's Pocket Book of Mechanics and Engineering.* 19th edition, revised and corrected by W. D. MARKS. 670 pp. Philadelphia, 1887 (J. B. Lippincott Company).—This volume is truly remarkable for the variety and extent of the information it contains. No one who has learned by experience the value of having such an assistant at hand will be willing to be without it. The present edition has had the benefit of revision by Professor Marks which commends it to a still wider circle of readers.

2. *Sixth Annual Report of the U. S. Geological Survey*, by J. W. POWELL, Director, 1884–85.—Of the papers published in this report, Mount Taylor and Zuñi Plateau, by Capt. C. E. Dutton, has been already noticed in this Journal. The others are "Preliminary papers on the driftless area of the Upper Mississippi valley, by T. C. Chamberlin and R. D. Salisbury, pp. 199 to 352; Preliminary report on Sea-coast Swamps of the Eastern United States, by N. S. Shaler, pp. 359 to 398, and Synopsis of the Flora of the Laramie Group, by Lester F. Ward, pp. 399 to 558, illustrated by 65 double plates representing fossil leaves.

3. Dr. WOLCOTT GIBBS has resigned the Rumford Professorship in Harvard University, and will continue his scientific work at Newport, R. I.

# APPENDIX.

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ART. XLV.—*Principal Characters of American Jurassic Dinosaurs.* Part IX. *The Skull and Dermal Armor of Stegosaurus;* by O. C. MARSH. (With Plates VI, VII, VIII, and IX.)

IN previous numbers of this Journal, the writer has given the more important characters of the skeleton of the *Stegosauria*, and has indicated the relations of this group to the other known *Dinosauria.** The discovery of additional specimens of *Stegosaurus*, one of them nearly complete, furnishes material to greatly enlarge our knowledge of the skull and dermal covering of this genus, and some of the new facts are placed on record in the present article.

The results of the entire investigation of this group will be brought together in a monograph now in preparation, by the writer, for the U. S. Geological Survey. The lithographic plates for this volume, sixty-five in number, are nearly all printed, and the figures of the skull here given are taken from these plates.

* This Journal, vol. xiv, p. 513, Dec., 1877; vol. xix, p. 253, March, 1880; vol. xxi, p. 167, Feb., 1881; and vol. xxiii, p. 83, Jan., 1882.

### The Skull.

The skull of *Stegosaurus* is long and slender, the facial portion being especially produced. Seen from the side, with the lower jaw in position, it is wedge-shaped, with the point formed by the premaxillary, which projects well beyond the mandible, as shown in figure 1, Plate VI. The anterior nares (*a*) are large, and situated far in front. The orbit (*b*) is very large, and placed well back. The lower temporal fossa (*c*) is somewhat smaller. All these openings are oval in outline, and are on a line nearly parallel with the top of the skull. In this view, the lower jaw covers the teeth entirely.

Seen from above, as shown in figure 3, Plate VI, the wedge-shaped form of the skull is still apparent. The only openings visible are the supra-temporal fossæ (*e*). The premaxillary bones (*pm*) are short above, but send back a long process below the narial orifice. The nasal bones (*n*) are very large, and elongate. They are separated in front by the premaxillaries, and behind, by anterior projections from the frontal bones. The prefrontals (*pf*) are large, and are placed between the nasals and the prominent, rugose supra-orbitals (*so*). The frontals are short, and externally join the postfrontals (*fp*). The parietals are small, and closely coössified with each other.

Viewed from in front, the skull and mandible present a nearly quadrate outline (Plate VI, figure 2), and the mutual relations of the facial bones are well shown. In this view is seen, also, the predentary bone (*pd*), a characteristic feature of the mandible in this genus. The lateral aspect of this bone in shown in figure 1.

The teeth in this genus are entirely confined to the maxillary and dentary bones, and are not visible in any of the figures here given. They are small, with compressed, fluted crowns, which are separated from the roots by a more or less distinct neck. The premaxillary and the predentary bones are edentulous.

The present skull belongs to the type specimen of a new and very distinct species, which may be called *Stegosaurus stenops*. The skull and nearly complete skeleton of this specimen, with nearly all the dermal armor in place, were found almost in the position in which the animal died.

This animal was much smaller than those representing the other species of this genus. Its remains were found by Mr. M. P. Felch, in the Atlantosaurus beds of the Upper Jurassic, in southern Colorado. In this geological horizon, all the known American forms of *Stegosauria* have been discovered.

### The Dermal Armor.

The osseous dermal covering of the *Stegosauria* was first described by the writer, from specimens found associated with several skeletons, but not in place, and hence, the position of the various parts was a matter of considerable doubt. Subsequent discoveries have shown the general arrangement of the plates, spines, and ossicles, and it is now evident that, while all the group were apparently well protected by offensive and defensive armor, the various species, and perhaps the sexes, differed more or less in the form, size, and number, of portions of their dermal covering. This was especially true of the spines, which are quite characteristic in some members of the group, if not in all.

The skull was evidently covered above with a comparatively soft integument. The throat and neck below were well protected by small, rounded and flattened ossicles having a regular arrangement in the thick skin. One of these ossicles is shown in Plate VII, figure 1. The upper portion of the neck, back of the skull, was protected by plates, arranged in pairs on either side. These plates increased in size farther back, and thus the trunk was shielded from injury. From the pelvic region backward, a series of huge plates stood upright along the median line, gradually diminishing in size to about the middle of the tail. One of these is shown in Plate VII, figure 3. Some of the species, at least, had somewhat similar plates below the base of the tail, and one of these bones is represented in figure 2 of the same plate.

The offensive weapons of this group were a series of huge spines arranged in pairs along the top of the distal portion of the tail, which was elongate and flexible, thus giving effective service to the spines, as in the genus *Myliobatis*.

In *Stegosaurus ungulatus*, there were four pairs of these spines, diminishing in size backward. Two of the larger of these are shown on Plate VIII, figures 2 and 3. In some other forms, there were three pairs, and in *S. stenops*, but two pairs have been found.

In one large species, which may be called *Stegosaurus sulcatus*, there is at present evidence of only one pair of spines. These are the most massive of any yet found, and have two deep grooves on the inner face, which distinguish them at once from all others known. One of these grooved spines is represented on plate VIII, figures 4, 5, and 6.

The position of these caudal spines with reference to the tail is indicated in the specimen figured on Plate IX, which shows the vertebræ, spines, and plate as found.

The American genera of the *Stegosauria* are *Stegosaurus* and *Diracodon*. Of the former, there are several well-marked species besides *S. armatus*, the type. Of the latter genus, but one is known at present, *Diracodon laticeps*, the remains of which have hitherto been found at a single locality only, where several individuals referred to this species have been discovered. Aside from the form of the skull, these specimens have in the fore foot the intermedian and ulnar bones separate, while in *Stegosaurus*, these carpals are firmly coössified.

All the known American forms appear to have the second row of carpals unossified, and five digits in the manus. In the hind foot, the astragalus is always coössified with the tibia, even in very young specimens, while the calcaneum is sometimes free. The second row of tarsals is not ossified in any of the known specimens. Only four digits in the hind foot are known with certainty, and one of these is quite small. All forms have at least three well-developed metatarsals, which are short and massive, but longer and much larger than the metacarpals. Most of the bones originally referred to the hind foot of *Stegosaurus ungulatus*, and figured as such (this Journal, vol. xxi, Plate VIII), although found with the posterior extremities, subsequently proved to belong to the fore foot of another larger species.

In one large specimen, of which the posterior half of the skeleton was secured, no trace of dermal armor of any kind was found. If present during life, as indicated by the massive spines of the vertebræ, it is difficult to account for its absence when the remains were found, unless, indeed, the dermal covering had been removed after the death of the animal, and previous to the entombment of the skeleton where found. In this animal, the ilia were firmly coössified with the sacrum, thus forming a strong bony roof over the pelvic region, as in birds.

This specimen represents a distinct species, which may be called *Stegosaurus duplex*. It was originally referred by the writer to *S. ungulatus*, and the pelvic arch figured under that name.* In the sacrum of this species, each vertebra supports its own transverse process, or rib, as in the *Sauropoda*, while in *S. ungulatus*, the sacral ribs have shifted somewhat forward, so that they touch, also, the vertebra in front, thus showing an approach to some of the *Ornithopoda*.

* This Journal, vol. xxi, Plate VII, Feb., 1881.

The large number of specimens of the *Stegosauria* now known from the American Jurassic, and the fine preservation of some of the remains, enable us to form a more accurate estimate of the relations of the group to the other Dinosaurs, than has hitherto been possible. The presence of a predentary bone, and the well-developed post-pubis, are important characters that point to the *Ornithopoda* as near allies, with a common ancestry. These positive characters are supplemented by some points in the structure of the skull, and the form of the teeth.

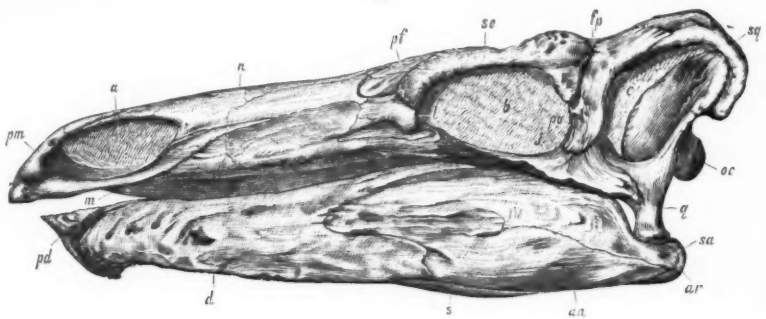
There are, however, a large number of characters in which the *Stegosauria* differ from the *Ornithopoda*, and among these are the following:

(1) All the bones of the skeleton are solid.
(2) The vertebræ are all biconcave.
(3) All the known forms have a strong dermal armor.
(4) The second row of carpals and tarsals are unossified.
(5) The astragalus is coössified with the tibia.
(6) The spinal cord was greatly enlarged in the sacral region.

The relations of these two groups to each other and to the rest of the known *Dinosauria* will be fully discussed by the writer in his monograph on the *Stegosauria*.

New Haven, Conn., October 24, 1887.

1.

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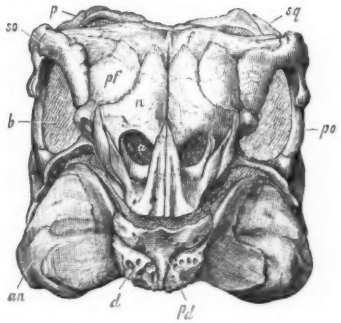


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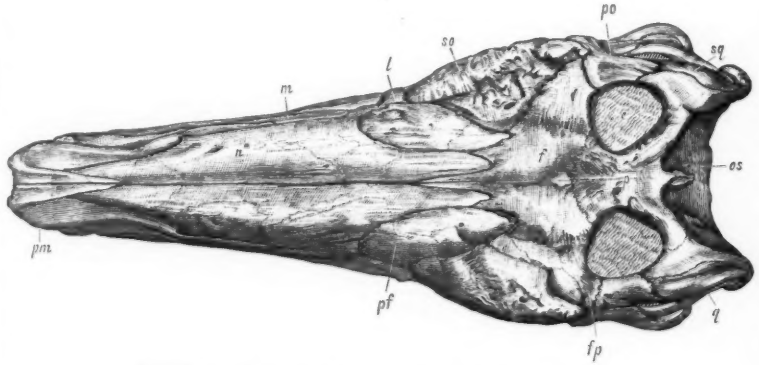



FIGURE 1.—Skull of *Stegosaurus stenops*. Marsh; side view.
FIGURE 2.—The same specimen; front view.
FIGURE 3.—The same specimen; top view.
All the figures are one-fourth natural size.

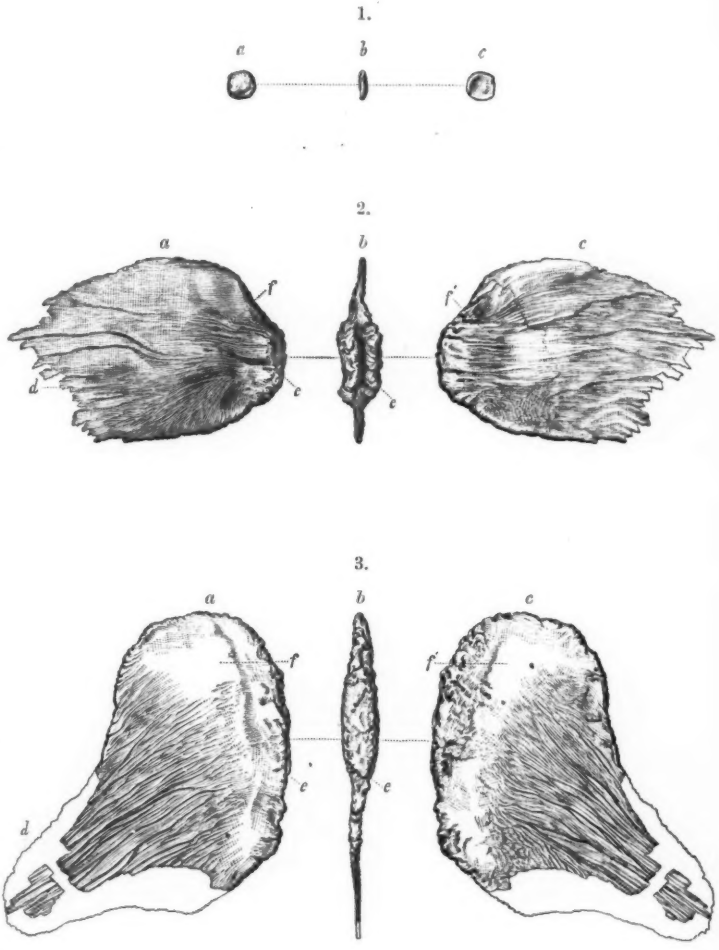



FIGURE 1.—Gular plate of *Stegosaurus ungulatus*, Marsh; *a*, superior view; *b*, side view; *c*, inferior view.

FIGURE 2.—Caudal plate of same individual; *a*, side view; *b*, end view of base; *c*, view of opposite side; *d*, thin margin; *e*, rugose base; *f*, and *f'*, surface marked by vascular grooves.

FIGURE 3.—Dorsal plate of same individual; *a*, right side; *b*, thick basal margin; *c*, left side; other letters as in last figure.

All the figures are one-twelfth natural size.

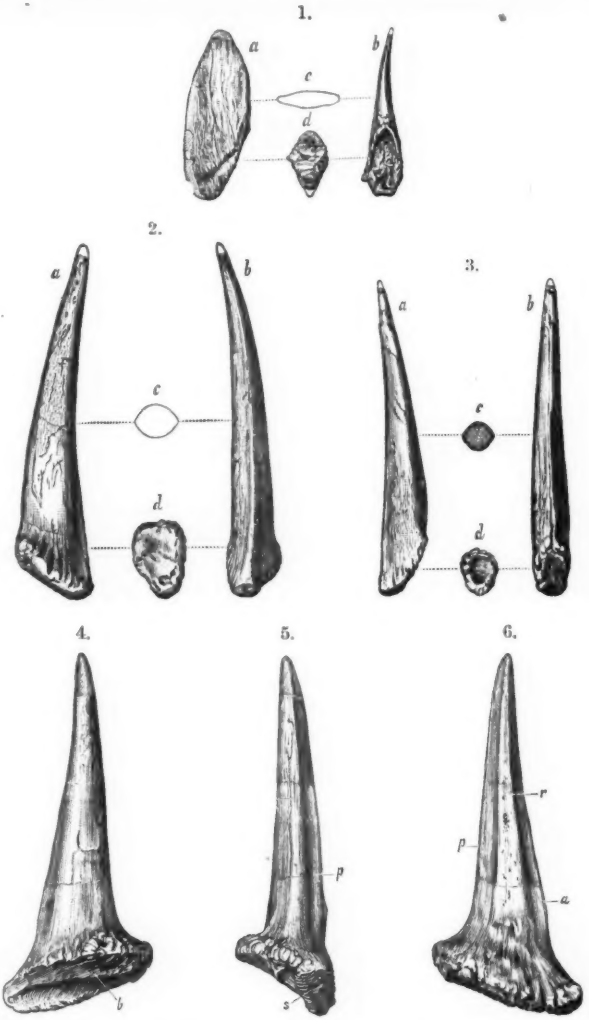



FIGURE 1.—Dorsal spine of *Stegosaurus ungulatus*, Marsh; *a*, side view; *b*, posterior view; *c* section; *d*, inferior view of base.

FIGURE 2.—Large caudal spine of same individual; *a*, side view; *b*, front view; other letters as above.

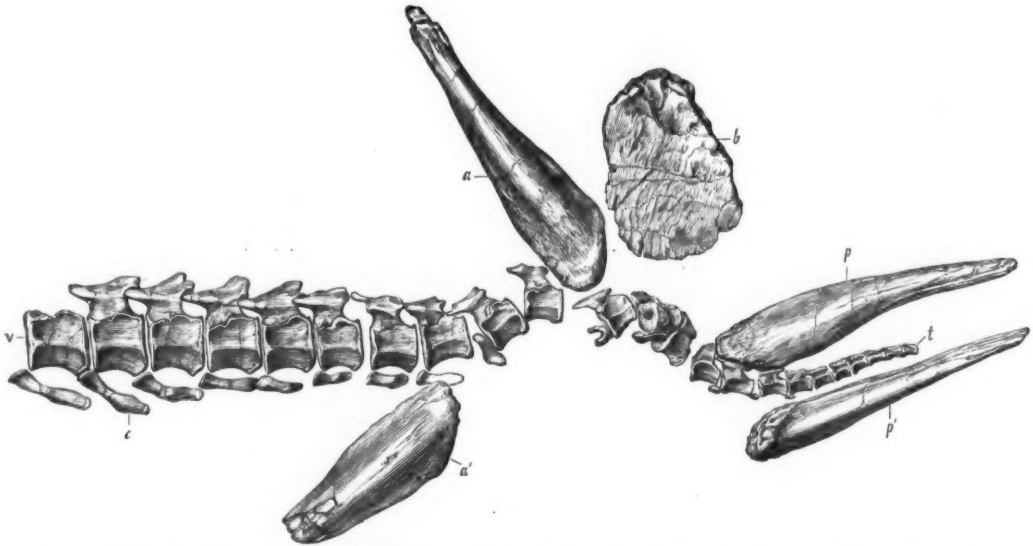
FIGURE 3.—Smaller caudal spine of same individual; *b*, posterior view; other letters as above.

FIGURE 4.—Caudal spine of *Stegosaurus sulcatus*, Marsh; side view.

FIGURE 5.—The same spine; posterior view.

FIGURE 6.—The same spine; inner view.

All the figures are one-twelfth natural size.




Caudal vertebræ, spines, and plate of *Diracodon laticeps*, Marsh; seen from the left. One-sixth natural size.
*a*, right anterior spine; *a'*, left anterior spine; *b*, small caudal plate; *c*, chevron bone; *p*, right posterior spine; *p'*, left posterior spine; *t*, terminal vertebra; *v*, median caudal vertebra.

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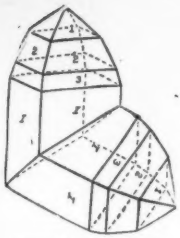

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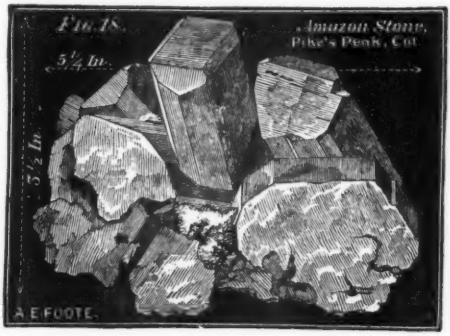


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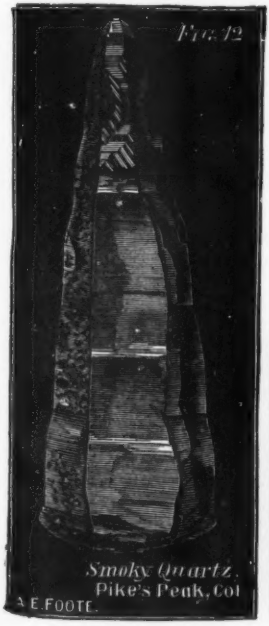


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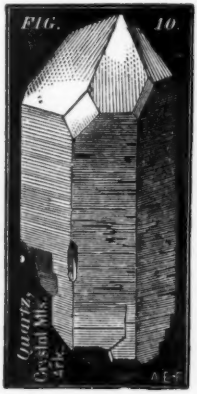

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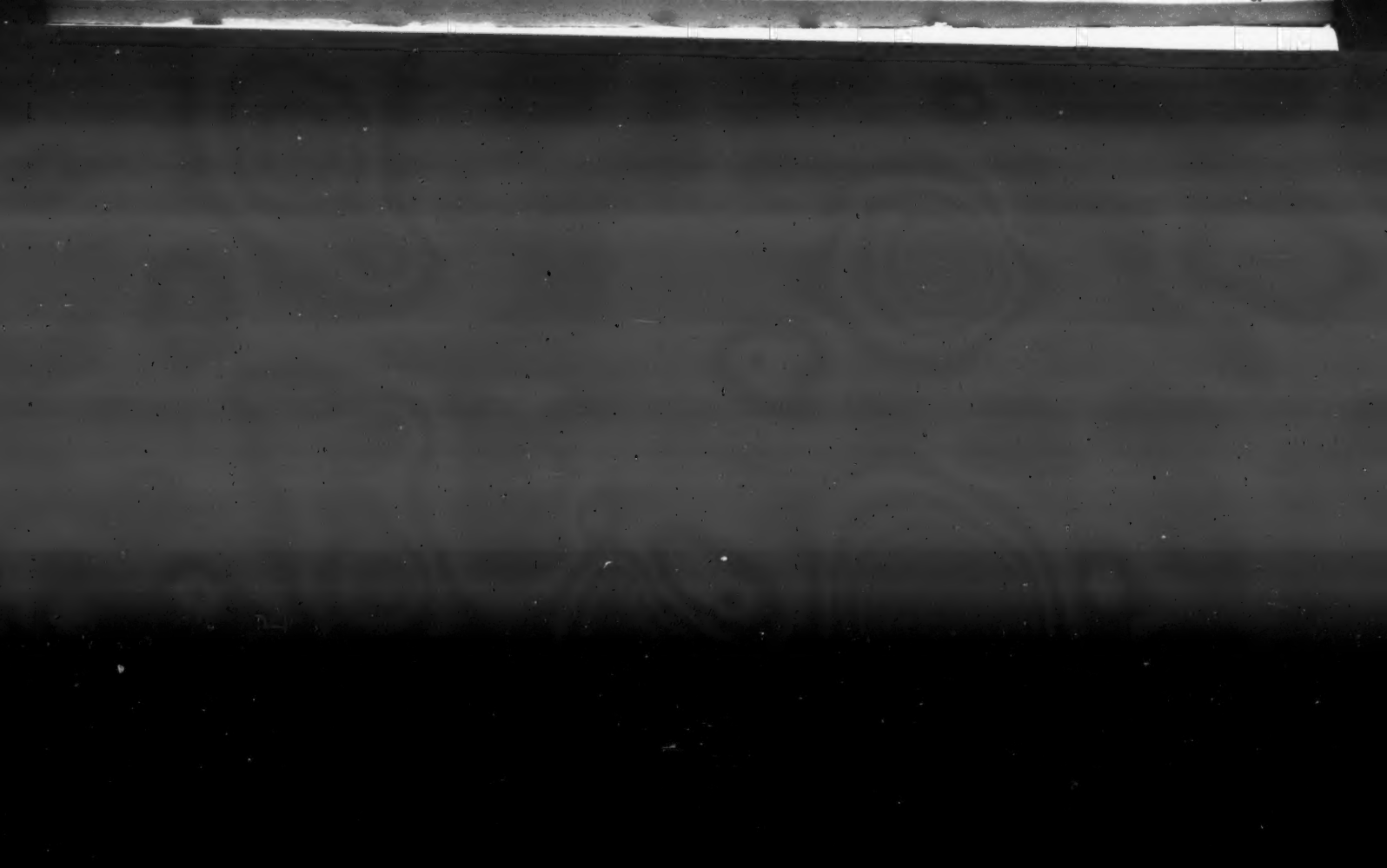

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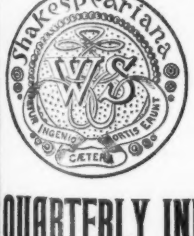


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